PRODUCTION PHYSIOLOGY OF POLYHOUSE TOMATO (*Lycopersicon esculentum* Mill)

By

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THESIS

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for the degree of

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DECLARATION

I, hereby declare that this thesis entitled **"Production physiology of polyhouse tomato (*Lycopersicon esculentum* Mill.)"** is a bonafide record of research work done by me during the course of research and that it has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Production physiology of polyhouse tomato (*Lycopersicon esculentum* Mill.)"** is a bonafide record of research work done independently by **Ms. Margaret Thomas** under my guidance and supervision and that it has not formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Margaret Thomas

Dedicated to
my dearest
parents

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Introduction

1. INTRODUCTION

After the advent of green revolution, more emphasis is laid on the quality of product along with the quantity of production to meet the ever growing food requirements. But these demands can be met only when the environment for plant growth is suitably controlled. The need to protect the crops against unfavourable environmental conditions led to the development of protected agriculture. Greenhouse is the most practical method of achieving the objectives of protected agriculture, where the natural environment is modified by using sound engineering principles to achieve optimum plant growth and yield.

The need of the hour is to increase the productivity of crops and quality of produce to assure food and nutritional security to the ever increasing human and animal population. Protected cultivation is the best alternative and drudgery less approach for using land and other resources efficiently. Greenhouse structures have distinct effect on several environmental parameters particularly temperature, light, carbon dioxide and humidity. The plant response to specific environmental parameter is related to the physiological processes and to yield and quality. Since the microclimate components inside the structures influences the functional aspects of plant, the emphasis is normally given to the maintenance of the optimal level of the factors for the successful and better productivity in the protective cultivation. The maintenance of crop photosynthesis is essential under the protective structure as it is responsible for 90% dry matter accumulation and plant productivity. The process is strongly influenced by radiation, CO_2 concentration and temperature (Bhatt, 2004).

Tomato is one of the most popular vegetable crops grown widely under protected cultivation. Tomato is known to thrive best when there is plenty of sunshine, low to moderate temperature at night (15-20°C) and warm days (25-

30°C). Yield of field crops usually range between 40 and 100 t/ha, whereas yields from year round cultivation in greenhouses in foreign countries is in the range of 500- 700 t/ha (Heuvelink and Dorais, 2005).

Tomato is a crop having good demand throughout the year in our state but, commercial cultivation of tomato is limited to Chittoor tract of Palghat district and that too during October- January. Most of the demand is met from neighbouring states like Tamilnadu and Karnataka. Preliminary studies at Kerala Agricultural University have shown that naturally ventilated polyhouse are ideal structures for off-season tomato cultivation in Kerala (Indira *et al.*, 2004). Hence by utilizing this technology, tomato production of our state can be enhanced.

High productivity is associated with good interaction between genotype, management and environment. For the proper growth and better yield of the crop under protected structure, it is essential to understand the functional behaviour of the plant. The crop productivity is the after effect of short term (photosynthesis, transpiration and stomatal conductance) and long term (flowering, fruiting and photoassimilate translocation) physiological processes. Hence, this study was attempted to look into the physiological reasons attributing to yield of tomato in polyhouse condition as the main objective.

Review of literature

2. REVIEW OF LITERATURE

Maximization of crop yield is associated with good interaction between genotype, environment and management. Protected cultivation is the best alternative and drudgery less approach for using land and other resources more efficiently. For proper growth and better yield of crop under the protected structure, it is essential to understand the functional behavior of the plant. Generally crop productivity under these structures is affected primarily by short term and long term physiological processes. This chapter provides a review of the relevant literature available in India and abroad on the effect of weather and growing conditions on various growth factors, physiological parameters and productivity of greenhouse vegetable crops. The available literature is reviewed under the following major heads.

2.1 Effect of growing conditions on growth and yield of greenhouse vegetable crops
2.2 Influence of weather parameters on growth and yield of greenhouse vegetable crops
2.3 Incidence of pests and diseases

2.1 EFFECT OF GROWING CONDITIONS ON GROWTH AND YIELD OF GREENHOUSE VEGETABLE CROPS

2.1.1 Vegetative and growth parameters

a. Plant height

Plants grown under greenhouse grew more vigorously than in open field. They exhibited greater plant height. It is due to the cellular expansion and cell division under shaded conditions (El-Aidy *et al.*, 1988). Lal *et al.* (1991) reported the highest mean plant height of 98.30 cm in Pant-74 and the lowest mean of 50.09 cm in cultivar Azad Kranti in tomato.

Abou- Hadid *et al.* (1994) reported that tomato plants grown under tunnels in Egypt showed a highly significant plant height in various stages of development against open condition. Arin and Ankara (2001) reported 643.72 percent increase in height relative to height at the planting time in tomato plants grown under low tunnel than those grown without tunnel in which it was 602.87 percent.

Tomato crop grown under greenhouse conditions attained more plant height of 84.10 cm against 69.03 cm in the open field (Ganesan and Subashini, 2001). Plant height of tomato was found to be higher under polyhouse condition compared to open field condition during both kharif and summer seasons (Anbarasan, 2002). Tomato plants grown under plastic tunnels of any gauge had more plant height compared to uncovered plants (Kumar and Srivastava, 2002).

The tomato plants grown under shade exhibited better growth in terms of plant height and dry matter production compared to those in open field (Thangam *et al.*, 2002). Sethi *et al.* (2003) reported that growth of muskmelon inside greenhouse was much higher as compared to open plants. It was observed that the average growth rate of inside plants was 4mm per day whereas it was 2mm per day for outside plants.

b. Number of branches per plant

Ganesan and Subashini (2001) found that crops grown under greenhouse conditions showed better growth in terms of number of branches. Greenhouse tomato had a mean of 38.73 whereas it was only 26.4 in open field crop. Kumar and Srivastava (2002) reported that tomato plants without cover had lesser number of branches compared to plants under low tunnels of any gauge. They also found that Pant Bahar, an indeterminate variety exhibited higher number of branches than determinate Pusa Early Dwarf. Number of primary branches was higher in open field compared to protected structure during both rainy and summer season in most of the tomato genotypes tried (Thangam *et al.*, 2002).

c. Inter nodal length

Ganesan (2002) reported that plants raised in the poly-greenhouse had longer internodes compared to those grown in open field. Number of nodes also was more inside greenhouse. Polyethylene covered plants received comparatively lower light intensity than uncovered plants. The shading would have increased cell elongation, which increased the length of internodes resulting in increased plant height (Kumar and Srivastava, 2002).

d. Relative Growth Rate (RGR)

Bhella (1988) observed that in tomato cultivar under polythene mulching plant spread and dry matter production were significantly increased over non mulched crop. Markedly improved tomato growth in terms of dry matter content under the polyethylene tunnels compared to uncovered control was reported by Mitra *et al.* (1990). He concluded that the improved vegetative growth under the low plastic tunnels might largely be attributed to favorable microclimate under polyethylene covers.

Bakker (1991) reported a small but significant increase in RGR in response to an increase in day time humidity for tomato seedlings. Fayad *et al.* (2001) conducted a trial with tomato variety Santa Clara with seven clusters in open field and a hybrid EF- 50 pruned at eight cluster stage in plastic greenhouse. Relative growth rate was 87.0 mg /g/day in first case whereas in the latter case it was 54.0 mg /g/day.

e. Leaf Area Index (LAI)

Leaf area index is a major determinant of crop growth rate and temperature is the main determinant of leaf area development (Watson, 1952).

High temperature increased the rate of the leaf initiation and appearance (Milthrope, 1959). De koning (1993) and Heuvelink (1999) found LAI values as low as 1.5 or 2.0 in summer. De kreij (1995) reported that in tomato, high humidity in winter or early spring caused low leaf area, which negatively influenced production.

Scholberg *et al.* (2000) reported that polyhouse tomato had higher leaf area index of 5.94 in both summer and kharif season whereas it was only 4.26 and 4.31 respectively under open field condition at 60 days after transplanting. For optimum light interception and fruit yields of a field grown tomato crop, the LAI should be around 4 to 5. Lower LAI values would reduce light interception and increase yield loss due to sunburn while higher values may delay the onset of fruit production. (Scholberg *et al.*, 2000).

Low LAI resulted in reduction of crop photosynthesis and yield (Heuvelink *et al.*, 2005). The strong assimilate demand by the growing fruits at the higher temperatures reduced leaf growth in greenhouse (Heuvelink and Dorais, 2005). The amount of intercepted light is a predominant factor in tomato crop growth and biomass production and depends mainly on leaf area. This relationship can be described as a negative exponential function of leaf area index. At a leaf area index of 3, an indeterminate tomato crop intercepts theoretically about 90 percent of incident light. (Cavero *et al.*, 1998)

Low light levels observed in late autumn (October and November) and changes in crop light interception as influenced by leaf area development may also reduce growth rate (Heuvelink and Dorais, 2005). Early growth of crop is exponential at low LAI, photosynthetic photon flux density (PPFD) interception, crop growth rate and photosynthesis are linearly related to leaf area index (Challa *et al.*, 1995).

f. Crop Growth Rate (CGR)

Crop growth rate is linearly related to crop photosynthesis (Penning de Vries and Van Laar, 1982). Maximum crop growth rate occurs when plants are large enough or dense enough to exploit all the environmental factors to the greatest degree. Growth rate is low at early phase of growth because of incomplete cover and the low percentage of sunlight interception (Tesar, 1984).

Ehler and Karlsen (1993) reported that lower Photosynthetic Photon Flux Density (PPFD) found inside greenhouse compared to ambient with corresponding decrease in gross photosynthesis is a constraint for crop production in greenhouse.

g. Net Assimilation Rate (NAR)

In short term studies, humidity had little effect on RGR and NAR of tomatoes grown under low light conditions (Hurd, 1973). NAR and LAR are often mutually dependent showing a negative correlation (Thornley and Hurd, 1974). Net assimilation rate is highest when plants are small and leaves are few enough that none are shaded by others. As plants grow, NAR decreases. (Tesar, 1984)

Grange and Hand (1987) observed that at high humidity, NAR is reduced. Mutual shading of leaves beginning within a few weeks of crop emergence is a major reason for a rapid decline of both RGR and NAR (Goudriaan and Monteith, 1990). The NAR of tomato seedlings was maximum when the mean daily light integral was 400 J per cm^2 or more. At high radiation, the NAR response of young tomato plants to changes in radiation was partly compensated by adaptations in LAR (Bakker *et al.*, 1995).

Study conducted by Venema *et al.* (1999) revealed that NAR was not influenced by low temperature for tomato. Heuvelink and Dorais (2005) reported that growth analysis in young tomato plants, confirms the main effect of temperature on RGR which may be attributed to its effect on leaf area ratio (LAR) whereas there is only a minor effect on net assimilation rate.

2.1.2 Reproductive characters

a. *Days to flower*

Grimstad (1995) indicated that low temperature delayed flowering. Ho (1996) observed that under low light conditions, initiation of first inflorescence is delayed in tomato, as more leaves are initiated prior to the inflorescence. In an indeterminate plant, temperature affects floral initiation, floral development, and fruit set and fruit growth simultaneously.

Ajithkumar (1999) found that morning and afternoon relative humidity during the first and second weeks after planting had positive effect on the days to first flowering. He also reported that it has a negative correlation with bright sunshine during first to second week after planting.

Anbarasan (2002) reported that kharif tomato crop took 60.71 days and summer crop took 55.09 days for fifty percent flowering in open field whereas it was 58.65 and 59.40 days respectively for polyhouse crop. Vezhavendan (2003) observed earliest flowering of capsicum in rainshelter compared to open field condition.

ICAR (2004) observed no significant difference with regard to earliness of tomato variety Anagha under rainshelter and open field during summer. But during rainy season, there was significant difference. Open field crop flowered at 62.17 days after planting whereas under rainshelter with roof ventilation, it was 65.7 days.

b. *Days to harvest*

Slack and Calvert (1978) found a positive correlation in tomato between increasing night temperature and early fruit yield, but final yield was negatively correlated to temperature. Gent (1988) found that under a day night temperature difference of 9°C, greenhouse tomato fruits grew and ripened quickly, resulting in greater early yield.

Grimstad and Frimanslund (1993) reported that an average daily temperature of 15 to 25°C reduced the time to first cucumber harvest in greenhouse by 1.6d°C^{-1}. Grimstad (1993) observed that low temperature resulted in a delayed harvesting of tomato in greenhouse.

Moccia *et al.* (1999) noted that determinate variety Lilliput of tomato exhibited early yield. Open crop of tomato took less number of days to maturity compared to crop under rainshelter (AVRDC, 2000). Study conducted by Arin and Ankara (2001) indicated that low tunnels are useful for promoting early harvesting and high total yield when compared with uncovered crop.

Vezhavendan (2003) noted that capsicum under rainshelter took less number of days to harvest than open crop in both rabi and kharif season in Kerala. Early flowering and fruiting were noticed in open field when compared to shade for different genotypes of tomato tried (Thangam *et al.*, 2002). ICAR (2004) noted that tomato under rainshelter harvested earlier than open crop during rabi but during rainy season, open field crop was harvested earlier than covered crop.

c. *Number of inflorescences*

Day temperature was more important in determining truss number in tomato (Heuvelink, 1989). Under greenhouse conditions, cultivar Capello recorded the average number of flowers per truss as seven (Bertin and Gary, 1992). Cockshull (1992) observed the number of flower buds formed on each of first ten trusses varied between nine and eleven under glasshouse condition.

Rylski and Aloni (1994) reported that the temperature and irradiation conditions at early stages of flower development are important factors that determine fruit yield and quality. A low night temperature can induce the tomato seedling to produce a higher flower number (Ho, 1996).

Total number of flowers per tomato plant ranged from 19 to 79 in summer and 170 to 209 in rabi season under Jorhat conditions (Deepa and Abu, 1996). Hazarika and Phookan (2005) noted that in polyhouse, variety BT_1 produced the largest number of inflorescence and the minimum was counted in Arka Vikas. Such variations might be inherent genetical characteristics of the cultivar to produce flowers at high temperature.

d. *Fruit size*

Fruit size is independent of the assimilates produced by the foliage and the number of fruits competing for the assimilates. Potential size of tomato fruit is dependent on their position within a truss and cultivar (Ho, 1980). Anbu *et al.* (1981) recorded a mean score of 4.9 for fruit size in the hybrid LE 113 × LE 78.

Under extreme conditions of low humidity, total yield of tomato is reduced by a decrease in fruit size (Picken, 1984). But Bakker (1990) obtained low yields and reduced fruit size under high humidity.

Pearce *et al.* (1993) found that average fruit size decreased with temperature, being a consequence of increased truss appearance rate and accelerated fruit development. Muthuvel *et al.* (2000) observed smaller fruits in tomato plants grown under glasshouse which may be due to competition between the fruits for assimilates. Anbarasan (2002) observed larger fruits in tomato under polyhouse during both summer and kharif than crop in open field.

e. *Fruit weight*

Lower sink activity of sweet pepper fruits at low temperature reduces the mean fruit weight (Bakker and Van Uffelen, 1988). Naniwal *et al.* (1992) observed a range of 44.4g in Pusa Ruby to 81.89 g in MDT 21 for this trait. A range of 29.86 to 56.6 g of fruit weight was observed in a study conducted by Bhardwaj and Thakur (1994) with 26 genotypes of tomato during summer season.

At higher temperature an almost similar amount of assimilates has to be distributed over a large number of fruits resulting in a lower average fruit weight. Thus the potential fruit weight at 23°C is about 40 percent lower than at 17°C (De koning, 1994).

Yungini *et al.* (1997) recorded the highest single fruit weight of 13 g in Alai and the lowest of 9.60g in Sook during summer. Joshi *et al.* (1998) recorded an average weight of 61.12 gram per tomato fruit. Fruit weight of tomato was 38.3g under plastic shelter where as it was 33.7g in open condition (AVRDC, 2000).

Cucumber under polyhouse gave 239g and all the plants in open field gave very poor yield or got killed (Kanthaswamy *et al.*, 2000). Fruits obtained from polyhouse crop gave higher mean of 26.56g as compared to 25.10g in open field crop during summer. During kharif season, it was 24.74g and 22.19g respectively (Anbarasan, 2002)

ICAR (2004) recorded average fruit weight of 23.0g during rabi and 39.1 g during kharif inside rainshelter in tomato whereas it was 17.5g and 43.1 g respectively in open field. Hazarika and Phookan (2005) found that among different genotypes of tomato tried, cultivar Yash recorded significantly higher individual fruit weight of 86.03 over most of the cultivars in polyhouse.

f. Number of fruits per plant

Low 24 hour mean temperature increased the number of fruits per plant while reducing vegetative growth (Bakker and Van Uffelen, 1988). When tomato is grown in glasshouse, the single fruit size and fruit number can be affected by season largely through direct effect of solar radiation on crop photosynthesis and glasshouse air temperature (Cockshull and Ho, 1995).

Indoor culture with shed house produced highest number of fruits in tomato than open field (Weerakkody and Peiris, 1998). Muthuvel *et al.* (2000) observed that number of fruits per plant was the highest for LE 1265 for both open and glasshouse condition during kharif and were 67.56 and 44 respectively.

High temperature may reduce pollen quality increase floral anomaly and consequently reduced fruit number (Dorais *et al.*, *2001*). Tomato in the open field produced larger number of fruits with a mean of 14.91 in summer and 12.07 during kharif season compared to 7.75 and 7.85 under polyhouse condition respectively (Anbarasan, 2002).

Number of fruits was higher in rainshelter during both rabi and kharif season (ICAR, 2004). In a comparative performance study conducted by Pandey *et al.* (2005), all the lines produced higher number of fruits in glasshouse and polyhouse than in open field.

g. *Yield per plant*

Shelby *et al.* (1978) reported a slight but significant decline in pollen viability from plants subjected to high temperature. During winter in midhills of Uttar Pradesh, Bhatnagar *et al.* (1990) found that in the open field tomato plants were killed by frost. In greenhouse, a yield of 360 to 507 quintal per ha was obtained.

Dane *et al.* (1991) observed reduced pollen viability after prolonged period of higher temperature in the field, which resulted in poor fruit yield. Stress during fruiting stage would reduce productivity in tomato (Rao and Sree vijayapadma, 1991).

Isshiki (1994) observed a double yield of tomato in rainshelter than openfield. Fontes *et al.* (1997) recorded average marketable fruit yield of 3.15 kg per plant in plastic tunnel, which was 141 percent higher than in field grown plants with marketable fruits representing 94 and 71 percent of total yield. He also noted that the average yield of marketable fruits of two tomato cultivars Sunny and EF-50 in plastic tunnel was 51 percent higher than that of field grown plants.

In an experiment with long life type salad tomato cultivars, Gualberto *et al.* (1998) reported that marketable fruit yield was 40 to 45 percent higher in greenhouse than open field. Rainshelter cultivation of tomato at plastic culture development centre, Thavanur recorded an yield of 5 Kg per m^2 whereas it was only 1.3 Kg per m^2 in open condition (KAU, 1999).

Arya *et al.* (2000) reported that plastic shelter increased tomato and capsicum production by 169 and 956 percent without any use of pesticides. Chandra *et al.* (2000) recorded a higher yield of 110.5 t per ha with Naveen and 98.6 t per ha with Pusa Hybrid 2 varieties of tomato inside polyhouse.

A study conducted in TNAU in naturally ventilated polyhouse with insect proof net and openfield by Nagalakshmi *et al.* (2000) showed that S-41 under polyhouse was early in flowering and fruitset than open field and yield was double compared to openfield. Srivastava (2000) obtained 60 to 70 percent higher tomato yield under polyhouse in high rainfall areas of Jorhat, Assam. Dixit *et al.* (2002) found green leafy vegetables under greenhouse structure showed superior yield and yield attributing characters as compared to open field condition.

h. *Percentage of cracked fruits*

Cuticle cracking is common in greenhouse tomato production, where the percentage of harvested fruits affected vary from 10 to 95 percent of total fruits (Bakker, 1988., Demers *et al.*, 2001).

Percentage of cracked fruits and crack length were decreased by low humidity and increased by high humidity (Ohta *et al.*, 1991). Peet (1992) noted that increase in fruit temperature raised gas and hydrostatic pressure of the pulp on the skin resulting in immediate cracking in ripe fruits or delayed cracking in green fruits. He also found that under high light intensity, cracking is more.

Maroto *et al.* (1995) found that fruits from the plants grown in high humidity had a higher incidence of cracking. The incidence and severity is highest during the summer months and low in spring (Demers *et al.*, 2001., Khosla *et al.*, 2000).

Bender *et al.* (2005) studied the influence of weather condition on fruit cracking in six cultivars. Maike and Valve had higher cracking resistance with only 2 and 5 percent cracking. Most susceptible cultivars were Piibe F1 (43%) and Erk (29%) in dry and hot weather in 2002. In 2003 during wet and humid weather, Visa (34%) exhibited highest cracking.

2.2 EFFECT OF WEATHER PARAMETERS

a. Influence of temperature on growth and yield of greenhouse vegetable crops

Friend and Helson (1976) suggested that high growth rate obtained under a high day temperature was the result of a high rate of net photosynthesis. Nilwik (1981) observed changes in RGR during seedling stage in response to temperature. Kleinendorst and Veen (1983) noted a decline in NAR below a day temperature of 18°C in cucumber. Challa and Brouwer (1985) noted changes in RGR in response to temperature and a decline in NAR below a night temperature of 12°C in cucumber. Smeets and Garretsen (1986) and Heuvelink (1989) demonstrated that there are changes in RGR during seedling stage in response to temperature.

De koning (1988) reported a positive effect of increasing night temperature on final fruit yield and fruit size. Heuvelink (1989) reported that day temperature was more important than night temperature in determining the fresh and dry weight, plant length, leaf area and RGR of young tomato plants. Leaf number, the main component of total leaf area is a function of leaf appearance rate. Temperature is a major limitation to leaf appearance rate in crops (Kiniry *et al.*, 1991).

Young tomato plants were more affected by low temperature than older plants showing reduced net assimilation rates and reduced leaf growth (Voican and Leibig, 1991). Higher temperatures in the early stages of growth of tomato promoted leaf expansion (Cockshull, 1992)

Increase in fruit temperature resulted immediate cracking in ripe fruits or delayed cracking in green fruits (Peet, 1992). Growth of vegetative organs in aubergines and tomato in greenhouse was negatively influenced by highest temperature among 30.3, 32.1 and 34.0 °C. Treatment of higher night temperature than day temperature reduced plant height in tomato and cucumber at 21 and 61 days after sowing mainly due to a decrease in internodal length (Abou Hadid *et al.*, 1993). Fruit weight of capsicum reduced with increase in temperature whereas it increased in aubergines (La-malfa, 1993). Low temperature reduced the pollen count and thus reduced fruit set and yield. (Ercan *et al.*, 1994)

Romano *et al.* (1994) found that vegetative growth of plants was not affected by low temperature but yield was reduced. Studies conducted by Grimstad (1995) showed that low temperature pulse at the beginning of the daily light period was most effective for tomato giving higher plant height. Low temperature reduced leaf number and shoot dry weight. Flowering was delayed resulting in a delayed harvest. Tomato fruit set and fruit weight per plant decreased as mean daily temperature increased from 25 to 29°C (Peet *et al.*, 1996).

Langton and Cockshull (1997) reported that extension growth in tomato responded to the absolute day and night temperature rather than to difference between day and night temperatures. The optimum temperature for extension growth was rather higher for day temperature than night temperature. At higher air temperature, fruits matured before sufficient growth had occurred (Wada *et al.*, 1998).

A study conducted at Vellanikkara condition (Ajithkumar, 1999) showed that the maximum temperature range of 30.6-33.7 °C and a minimum temperature range of 22.1-24.3°C was found to be optimum for crop growth of tomato. He also reported that the maximum temperature range of 31.6-32.1°C and minimum temperature range of 24.1-24.3°C were optimum for early flowering whereas minimum temperature range of 22.1-23.3°C during sixth and eighth week after planting are optimum for the increased yield.

Mean yield per plant in all the genotypes of tomato tried was more reduced under high temperature in the field and glasshouse during summer than during kharif (Muthuvel *et al.,* 1999). During summer under polyhouse, number of branches and leaf area index were positively correlated with maximum temperature while RGR was not affected. Negative and non significant correlation was noted between maximum temperature and number of flowers per plant, fruit weight and yield per plant (Anbarasan, 2002).

High temperature induced softness and uneven ripening of fruits (Mulholland *et al.*, 2003). Average air temperature inside greenhouse was 10 to 12 degrees higher than the ambient air temperature (Sethi *et al.*, 2003). Daily average greenhouse temperature may be several centigrades higher than the ambient. Air temperature in an unconditional greenhouse later in the night or early in the morning may be slightly lower than the ambient air temperature due to thermal radiation exchange between greenhouse and the cloudless surroundings (Sirohi and Chandra, 2005).

b. Influence of relative humidity on growth and yield of greenhouse vegetable crops

Bakker (1988) reported that final yield of tomato was reduced by high humidity at night and had no significant effect by day time humidity. Bakker (1990) observed the effect of humidity on growth and propagation of glasshouse tomatoes, cucumber and sweet pepper. Humidity levels were observed to be 20 to

25 percent higher as compared to outside conditions. Growth of inside plants was increased by 30 percent and it took about 30 days lesser for the fruits to mature.

Major long term effect of humidity on greenhouse crops is through its effect on leaf area. Leaf expansion is favoured by high humidity. There was a small but significant increase in RGR in response to an increase in daytime humidity in tomato seedlings. The effect of humidity on RGR was attributed to the small increase in NAR (Bakker, 1991).

Shoot length and leaf area increased with increase in RH. Higher RH increased the number of flowers produced and reduced the time for flowering (Gislerod and Mortensen, 1991). Percentage of cracked fruits and crack length were decreased by low humidity and increased with high humidity (Ohta *et al.*, 1991). High humidity inside greenhouse reduced leaf dry weight (Adams and Holder, 1992).

In greenhouses, high humidity is a major concern in connection with fungal and bacterial diseases (Bailey, 1995). Maroto *et al.* (1995) observed that fruits from plants grown in high humidity had a higher incidence of cracking. High day and night humidity increased blossom end rot from the end of August (Pivot *et al.*, 1998).

Ajithkumar (1999) reported that at Vellanikkara condition, relative humidity of 70 to 86 percent and afternoon relative humidity of 59 percent were required for tomato. He also found that morning and afternoon relative humidity during first and second weeks after planting had positive effect on the days to first flowering while morning relative humidity was negatively correlated with yield.

Significant positive correlations were obtained between morning relative humidity and plant height and LAI. Evening relative humidity also had significant positive correlations with above characters (Anbarasan, 2002). Improved vegetative growth under low plastic tunnels may largely be attributed to increased air temperature and relative humidity (Kumar and Srivastava, 2002)

Peet *et al.* (2002) reported that fruit weight was most sensitive to high humidity at high temperature and most sensitive to high temperature at high humidity. In an open system of greenhouse ventilation where outside air is brought in, relative humidities are usually lower permitting transpiration rates to rise with solar radiation (Sirohi and Chandra, 2005)

c. Influence of light intensity on growth and yield of greenhouse vegetable crops

Bruggink (1987) stated that, in tomato, cucumber and sweet pepper seedlings, relative growth rate is not proportional to variations in light integrals. Bruggink and Heuvelink (1987) found that leaf area ratio, the ratio between leaf area and total biomass increased with declining light intensity, thus partly compensating for the net assimilating rate.

High light intensity may have a role in increasing cracking. Under high light conditions, fruit soluble solids and fruit growth rates are higher and are sometimes associated with increased cracking (Peet, 1992). The area and dry weight of leaves and dry weight of roots and stems were higher with an irradiance of 14.7 or 8.5 MJ $m^{-2}day^{-1}$ than with lower irradiances. Fruit yield was highest in plants receiving full sun and plants failed to fruit at an irradiance of –3.3 MJ $m^{-2}day^{-1}$ in greenhouse (Mohd Razi and Ali., 1994).

Shaheen *et al.* (1995) studied different light intensities under polyhouse condition on tomato. They found that increasing shade level reduced seedling fresh weight and dry weight in both winter and autumn. Highest NAR values were obtained in control treatment. Decreasing light intensities reduced the values of NAR. A solar radiation flux density of 200 cal $cm^{-2}day^{-1}$ was considered to be the lowest value for tomato growth (Estefanel *et al.*, 1998).

Ajithkumar (1999) reported that bright sunshine of 5.2-10.0 hours required for optimum growth of tomato under Vellanikkara condition. He also found that days to first flowering showed a negative correlation with bright sunshine. The accumulated photosynthetically active radiation and sum temperature were significantly correlated with flowering and fruit set (Pek and Helyes, 2003).

2.3 PESTS AND DISEASE INCIDENCE

Irradiance, temperature and humidity levels within green house have a significant impact on the biology and dispersal of insect and mite pests and their biological control agents and the predatory parasitic interactions between them (Scopes, 1973). Crops stressed by adverse environment generally were more susceptible to diseases (Schoenweiss, 1975).

Alternaria solani and *Septoria lycopersici* in tomato occurred with less incidence inside green house (Bhatnagar *et al.*, 1990). Environmental control in the green house will be helpful for the biological control of plant diseases (Andrews, 1992).

The number of white flies visiting the plastic shelter plants was only 28 per cent of that in the open field (Arya *et al.*, 2000). Tomato spotted wilt is a major disease affecting green house cultivated tomato. High temperature increases severity of the disease (Mitidieri *et al.*, 2001). Blume and Jara (2004) reported that a relative humidity greater than 80 percent increased the incidence of diseases, which were primarily caused by fungi.

The diseases of viral origin are of the utmost important factors, which are limiting the tomato production. The viruses frequently reported in protected tomato crop in recent years are TYLCSV (Tomato yellow Leaf Curl Sardinia Virus), TYLCV (Tomato Yellow Leaf Curl Virus), TSWV (Tomato Spotted Wilt Virus), ToCV (Tomato Chlorosis Virus), TICV (Tomato Infectious Chlorosis Virus), CMV(Cucumber Mosaic Virus) and PepMV (Pepino Mosaic Virus). The first two are the most damaging ones at the moment (Davino *et al.*, 2004).

Materials and Methods

3. MATERIALS AND METHODS

The present investigation was carried out in the Department of Olericulture, College of Horticulture, Vellanikkara during 2005-2006 with the objective to study the production physiology of tomato grown inside the polyhouse as well as in the open field.

The site is located at 10°31'N and latitude, 76°13'E longitude and at an altitude of 22.25 m above MSL. The area experiences a typical warm humid climate and receives average rainfall of 2663 mm per year. The soil of the experimental site comes under the textural class of sandy clay loam and is acidic in reaction. The materials used and methods followed are presented below.

3.1 POLYHOUSE

Naturally ventilated, medium cost polyhouse with open sides constructed in the Department of Olericulture was used for the study (Plate 1). The frame of polyhouse is made up of GI pipes. Cladding is provided with UV stabilized Low Density Polyethylene (UVLDPE) film of 200 micron thickness. The floor area is 100 m^2 (20m × 5m) with a side height of 2m and central height of 3.5 m.

3.2 OPEN FIELD

Plain land adjacent to the polyhouse was utilized for evaluation under open field condition.

3.3 VARIETIES

Two tomato varieties viz, Anagha, bacterial wilt and crack resistant variety released from Kerala Agricultural University and LE 643 from ARS, Mannuthy were used for the study (Plate 2 and 3). The details of varieties are given in Table 1. They were evaluated during the period October 2005 - February 2006 in

Plate 1. Naturally ventilated polyhouse

Plate 2. LE 643

polyhouse and open field simultaneously in a completely randomized block design with four replications.

Table 1. Variety characteristics

Variety	Accession number	Growth habit
Anagha	LE 415	Semi determinate
LE 643	EC 398711	Indeterminate

3.4 CULTURAL OPERATIONS

3.4.1 Nursery practice

Nursery was raised in pots containing rooting medium of sand, soil and farm yard manure in the ratio 1:1:1 and were transplanted one month after sowing.

3.4.2 Preparation of main field and transplanting

The experimental site (polyhouse and open field) were cleared thoroughly inorder to avoid weeds during cropping period. The open field was ploughed twice, weeds were removed and was levelled. Ridges were taken 60cm apart. Farm yard manure was incorporated at the time of land preparation. One month old healthy seedlings were transplanted in furrows at a spacing of 60cm. Irrigation was given immediately after transplanting using a rose can. Shading was provided using green leaved twigs after transplanting and removed after three days. Gap filling was done within ten days after transplanting.

3.4.3 Fertilizers and application

Urea, Super phosphate and Muriate of potash were the source materials for supplying the nutrients N, P_2O_5 and K_2O respectively. A fertilizer dose of 75:40:25 kg was applied in split method as per package of practice (KAU, 2002).

3.4.4 After cultivation

The experimental area was kept free of weeds throughout the crop growth period by hand weeding. Light earthing up was given along with each fertilizer application.

3.4.5 Staking and training

Staking was done by using wooden sticks and tied with plastic thread to avoid lodging. For indeterminate variety, training was practiced using wooden poles and coir (Plate 4).

3.4.6 Plant protection

Leaf miner attack was controlled to some extent by two spraying of dimethoate @ 0.05 per cent. Quinalphos @ 0.05 per cent was applied against fruit borer. Plants which were severely attacked by leafcurl, mosaic and spotted wilt were uprooted.

3.4.7 *Harvesting*

Fruits were harvested at red ripe stage as indicated by colour change from green to red and fruit parameters were recorded.

3.5 OBSERVATIONS

Ten plants per replication of each variety from open and polyhouse conditions were selected for recording observations. Five well developed fruits were randomly selected from each plant for recording observations on fruit characters. Three plants from each replication were used for study of growth parameters through destructive sampling.

3.5.1 Vegetative characters

a. *Plant height (cm)*

Plant height was measured at 15 days interval starting from 15 days upto 45 days after transplanting and at final crop stage also. This was measured from the collar region of the plant to the growing tip.

b. *Branches per plant*

Number of branches per plant was counted at 15, 30 and 45 days after transplanting.

c. *Internodal length (cm)*

Internodal length was calculated from five internodes length starting from fifth to tenth node and mean was worked out.

3.5.2 Growth Parameters

a. *Relative growth rate (RGR)*

Relative growth rate is the basic component of growth analysis and is calculated using the concept of compound interest law in growth. Relative growth rate was determined by measuring plant dry weight periodically during growth period and was represented as g g^{-1} day^{-1}. Total dry weight of three plants at 15, 30 and 45 days after transplanting was recorded in each replication. RGR was calculated by using the formula given by Blackman (1919)

$$RGR = \frac{ln\ W_2 - ln\ W_1}{t_2 - t_1}$$ where,

W_1 and W_2 are the plant dry weight at time t_1 and t_2 respectively and *ln* is the natural logarithm.

b. Net Assimilation Rate (NAR)

Net Assimilation Rate was determined by measuring plant dry weight and leaf area periodically during growth and was represented as g $cm^{-2}day^{-1}$. It was calculated using the formula proposed by Gregory *et al* (1917), which was modified by Williams (1946).

$$NAR = \frac{(W_2 - W_1)(ln\, A_2 - ln\, A_1)}{(t_2 - t_1)(A_2 - A_1)}$$

where, W_1 and W_2 are plant dry weight at time t_1 and t_2 respectively. A_1 and A_2 are leaf areas at time t_1 and t_2 respectively and *ln* is the natural logarithm.

c. Leaf Area Index (LAI)

Leaf Area Index was calculated by dividing the area of leaves with ground area over which it is growing. (Watson, 1947)

$$LAI = \frac{A}{L}$$

A is total leaf area and L is the ground area. Leaf area was measured linearly by using the formula

$Y = -0.4 + 0.211\, X$ (Garg and Mandahar, 1972) where,

Y is calculated leaf area and X is the product of length and breadth of leaf.

d. Crop Growth Rate (CGR)

Crop Growth Rate was determined by measuring the plant dry weights of a particular ground at regular interval of time divided by land area and expressed as g m^{-2} day^{-1}. It was calculated using the formula given below (Watson, 1955)

$$CGR = \frac{W2 - W_1}{P\,(t_2 - t_1)}$$

where, W_1 and W_2 are plant dry weights at time t_1 and t_2 respectively and P is the spacing (m^2) . CGR was calculated at 15,30 and 45 days after transplanting.

3.5.3 Reproductive characters

a. Days to flower

The number of days taken from transplanting to opening of first flowering was recorded in ten plants and the mean was worked out.

b. Number of inflorescences

Number of inflorescences of ten plants from each replication was recorded and the mean was calculated.

c. Days to first harvest

The number of days from transplanting to harvest was recorded for ten plants in each replication and mean was used for analysis.

d. Fruit size

Fruits were classified as per the IBPGR descriptor for tomato based on equatorial diameter as given below.

i) Very small (<3cm)
ii) Small (3-5cm)
iii) Medium (5.1-8cm)
iv) Large (8.1-10cm)
v) Very large (>10cm)

e. Fruit weight (g)

Total weight of five fruits from ten plants in each replication was observed at second and third harvest and mean was worked out.

f. Yield per plant (Kg)

Fruit yield per plant was calculated for all the selected plants by adding yield of individual harvest and expressed in kilograms.

g. Number of fruits per plant

Total number of fruits per plant was counted at each harvest for all the selected plants and the mean was worked out.

h. Number of harvests

Total number of harvests made from ten plants was recorded in each replication and mean was worked out.

3.5.4 Biotic and abiotic factors

a. Incidence of pests and diseases

Observations on the incidence of major pests and diseases viz, leaf curl, mosaic, bacterial wilt and spotted wilt were recorded. The percentage of disease incidence was calculated using the following formula.

$$\text{Percentage of disease incidence} = \frac{\text{Number of plants affected by the disease} \times 100}{\text{Total number of plants}}$$

b. Percentage of cracked fruits

The number of cracked fruits in the total fruits was counted and expressed in percentage for the selected ten plants and mean was worked out.

3.5.5 Meteorological observations

The minimum and maximum temperature were observed daily using thermometer and relative humidity using dry and wet bulb thermometer in both conditions. Light intensity was measured daily using luxmeter both inside and outside polyhouse. Rainfall data was collected from the Agromet observatory of the College of Horticulture, Vellanikkara. The weekly weather data during the crop period are presented in Table 20 and 21.

3.6 STATISTICAL ANALYSIS

The data recorded on the vegetative and reproductive characters and meteorological observations were statistically analysed by using statistical package (MSTATC) (Freed, 1986). Simple correlations between the plant characters with the mean values of maximum and minimum temperature, relative humidity during morning and afternoon to determine the effect of weather elements on the growth and yield of tomato were computed. Canonical correlations were also computed between monthly weather data and plant characters. Partial correlations between crop yield and weekly weather data were calculated to study the effect of weather on yield.

Results

4. RESULTS

The observations recorded on various growth and yield characters and weather parameters during the experimental period were analysed statistically and the results are presented under the following headings:

4.1 Vegetative characters
4.2 Growth parameters
4.3 Reproductive characters
4.4 Crop weather relationship
4.5 Biotic and abiotic factors

4.1 VEGETATIVE CHARACTERS

4.1.1 Plant height

The data recorded on plant height is presented in Table 2. A steady increase in plant height was observed under polyhouse condition upto 45 days after transplanting. The crop had an extended phase of growth even after 45 DAT. Crop in open field recorded a mean height of 88.84 cm at final harvest stage as against 88.11 cm under polyhouse.

At 15 DAT, both varieties performed well under polyhouse and recorded 43.60 cm and 53.8 cm respectively for Anagha and LE 643. Lower heights (34.63 and 46.08 cm) were observed in open field. At 30 DAT also, height was more under polyhouse with a mean value of 67.03 cm against 63.16 cm in open field. LE 643 in polyhouse (Plate5) recorded 74 cm and 70.98cm heights in open field. Corresponding values were 60.05 cm and 55.35 cm for Anagha (Fig 1).

But at 45 DAT, crop in open field condition was taller with respective heights of 77.43 cm and 94.18 cm respectively for Anagha and LE 643 (Plate 6) as against 77.18 cm and 92.85 cm in polyhouse. At final harvest stage, Anagha

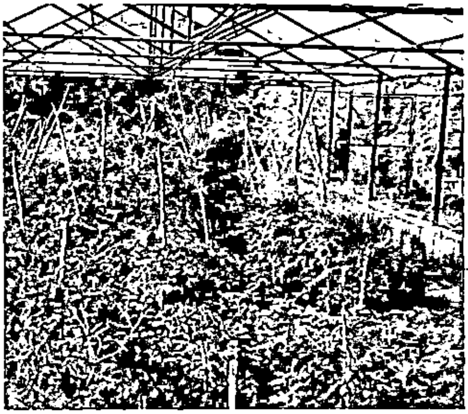

Plate 4. Tomato crop in polyhouse

Plate 5. LE 643 in polyhouse

Plate 6. LE 643 in open field

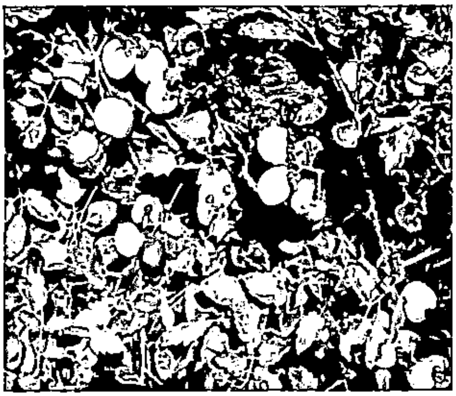

Plate 7. Anagha in polyhouse

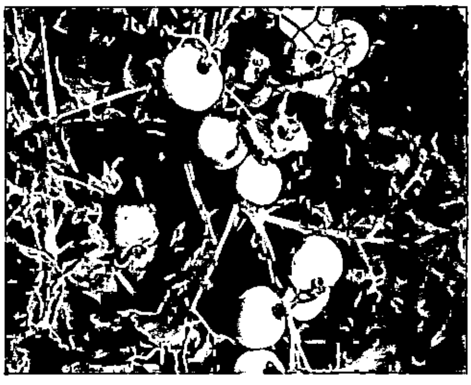

Plate 8. Anagha in open field

Table 2. Plant height (cm) as influenced by growing condition

Variety	15 DAT		30 DAT		45 DAT		Final harvest	
	Openfield	Polyhouse	Openfield	Polyhouse	Openfield	Polyhouse	Openfield	Polyhouse
Anagha	34.63	43.60	55.35	60.05	77.43	77.18	78.65	79.63
LE 643	46.08	53.83	70.98	74.0	94.18	92.85	99.03	96.60
Mean	40.35	48.71	63.16	67.03	85.80	85.01	88.84	88.11
SE	1.1826		1.8763		2.1634		8.1812	
CD (G)	2.675		NS		NS		NS	
CD (I)	NS		NS		NS		NS	

Table 3. Number of branches as influenced by growing condition

Variety	15 DAT		30 DAT		45 DAT	
	Openfield	Polyhouse	Openfield	Polyhouse	Openfield	Polyhouse
Anagha	3.1	2.2	7.5	6.6	12.3	12.1
LE 643	6.4	3.0	12.1	8.1	16.3	15.2
Mean	4.7	2.6	9.8	7.3	14.3	13.6
SE	0.3383		0.5476		0.5759	
CD (G)	0.7650		1.238		1.302	
CD (I)	1.082		1.752		NS	

G - Growing condition
I - Interaction between varieties and growing condition

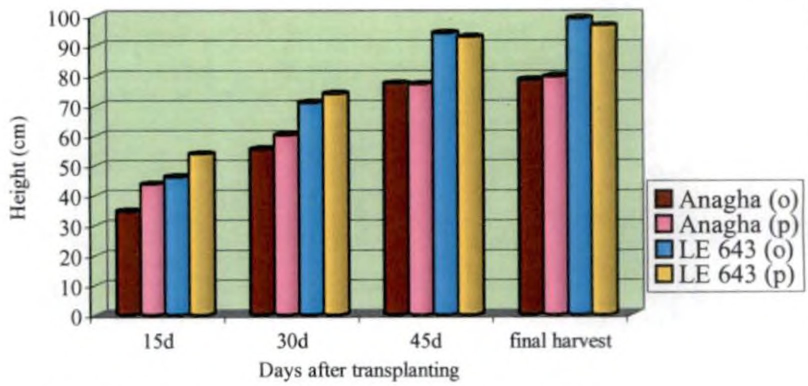

Fig. 1. Plant height as influenced by growing condition

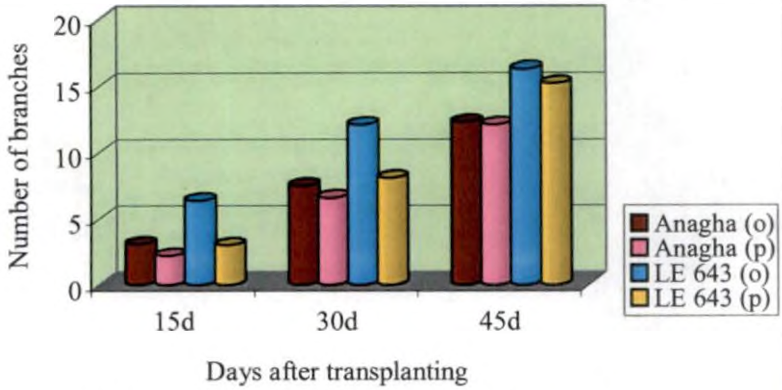

Fig 2. Number of branches as influenced by growing condition

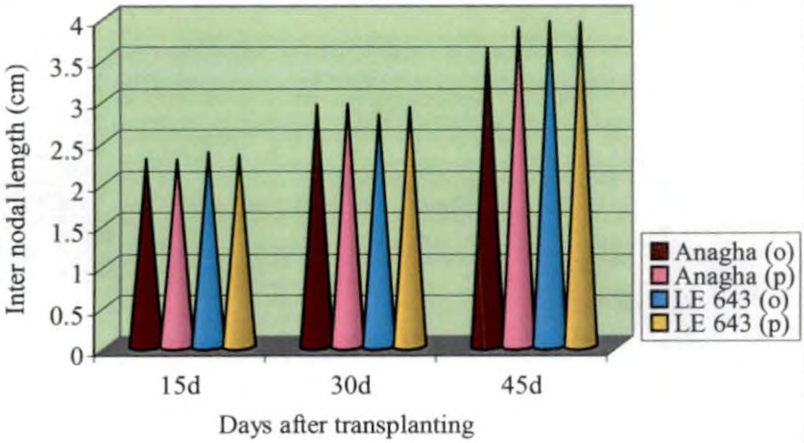

Fig 3. Internodal length as influenced by growing condition

recorded 79.63 cm in polyhouse (Plate 7) against 78.65 cm in open field. LE 643 was taller in open field and recorded 99.03 cm against 96.60 cm in polyhouse at this stage.

4.1.2 Number of branches

Observations on the number of branches are indicated in Table 3. Significant branching was observed in open field upto 30 DAT with mean values as 4.7 and 9.8 respectively at 15 and 30 DAT. Maximum number of branches was observed at 45 DAT. LE 643 exhibited significant branching habit in open field upto 30 DAT. The variety had profuse branching at all stages in contrast to Anagha irrespective of growing condition. At 15 DAT, Anagha had an average number of branches of 3.1 in open field as against 2.2 in polyhouse. LE 643 recorded 6.4 branches in open field (Fig 2).

At 30 DAT, LE 643 had 12.1 branches in open field and 8.1 branches in polyhouse and was statistically significant whereas Anagha had 7.5 and 6.6 branches respectively. The branching process was culminated with 16.3 and 15.2 branches for LE 643 in open field and polyhouse conditions with the corresponding figure as 12.3 and 12.1 for Anagha.

4.1.3 Internodal length

The data recorded on internodal length of varieties under two different growing conditions are presented in Table 4. The maximum value was obtained for LE 643 at 45 DAT and was equal under both growing conditions (3.93cm).

At 15 DAT, Anagha recorded 2.28 cm and 2.27 cm in open field (Plate 8) and polyhouse respectively with corresponding values as 2.35cm and 2.33 cm for LE 643 (fig 3). Open field crop recorded internodal length of 2.31 cm at this first stage of study. In contrast to the above situation, at 30 DAT internodal length was higher for tomato crop in polyhouse (2.92 cm) whereas in open condition it was recorded as 2.87 cm. At this stage LE 643 had an internodal length of 2.90 cm in polyhouse and 2.81 cm in open field whereas it was recorded as 2.94 cm and 2.93 cm respectively in Anagha.

Polyhouse crop had maximum average internodal length of 3.9 cm compared to 3.77 cm in open field at 45 DAT. Anagha had shorter internodes of 3.61 cm length in open field corresponding to 3.87cm in polyhouse at this stage. There was no difference in internodal length for LE 643 with respect to growing conditions. Differential internodal length of the two varieties under both growing conditions was non significant at all stages.

4.2 GROWTH PARAMETERS

4.2.1 Relative Growth Rate (RGR)

Relative growth rates calculated based on plant dry weights are presented in Table 5. During the first time interval, RGR was observed higher in open condition with mean value of 0.126 g $g^{-1}d^{-1}$ as against 0.098 g $g^{-1}d^{-1}$ in polyhouse which was higher than that in open field (0.047 g $g^{-1}d^{-1}$) and polyhouse (0.078 g $g^{-1}d^{-1}$) during 30-45 DAT.

During 15-30 DAT, Anagha expressed relatively higher growth rate of 0.13 g $g^{-1}d^{-1}$ in open condition compared to that of polyhouse crop (0.09 g $g^{-1}d^{-1}$). Relative growth rate was calculated as 0.122 g $g^{-1}d^{-1}$ and 0.107 g $g^{-1}d^{-1}$ respectively in open field and polyhouse for LE 643.Polyhouse crop exhibited higher growth rates of 0.087 g $g^{-1}d^{-1}$ and 0.069 g $g^{-1}d^{-1}$ at 30-45 DAT respectively for Anagha and LE643. Corresponding growth rates in open field were 0.059g $g^{-1}d^{-1}$ and 0.035 g $g^{-1}d^{-1}$(Fig 4).

4.2.2 Leaf Area Index (LAI)

Leaf Area Index computed at different stages of crop growth are given in Table 6. It showed an increase over the time period and differential significant

Table 4. Internodal length (cm) as influenced by growing condition

Variety	15 DAT		30 DAT		45 DAT	
	Open field	Polyhouse	Open field	Polyhouse	Open field	Polyhouse
Anagha	2.28	2.27	2.93	2.94	3.61	3.87
LE 643	2.35	2.33	2.81	2.90	3.93	3.93
Mean	2.31	2.30	2.87	2.92	3.77	3.90
SE	0.1079		0.1193		0.0958	
CD (G)	NS		NS		NS	
CD (I)	NS		NS		NS	

Table 5. Relative growth rate (RGR g/g/day) as influenced by growing condition

Variety	15-30 DAT		30-45 DAT	
	Open field	Polyhouse	Open field	Polyhouse
Anagha	0.13	0.09	0.059 (0.748)*	0.087 (0.766)
LE 643	0.122	0.107	0.035 (0.732)	0.069 (0.754)
Mean	0.126	0.098	0.047 (0.740)	0.078 (0.760)
SE	0.0120		0.0086	
CD (G)	0.027		0.0195	
CD (I)	NS		NS	

G - Growing condition
I - Interaction between varieties and growing condition
* Values in parenthesis are transformed values

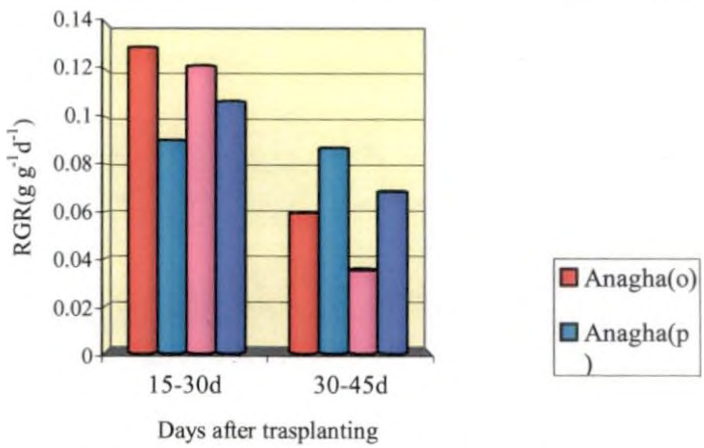

Fig. 4. RGR as influenced by growing condition

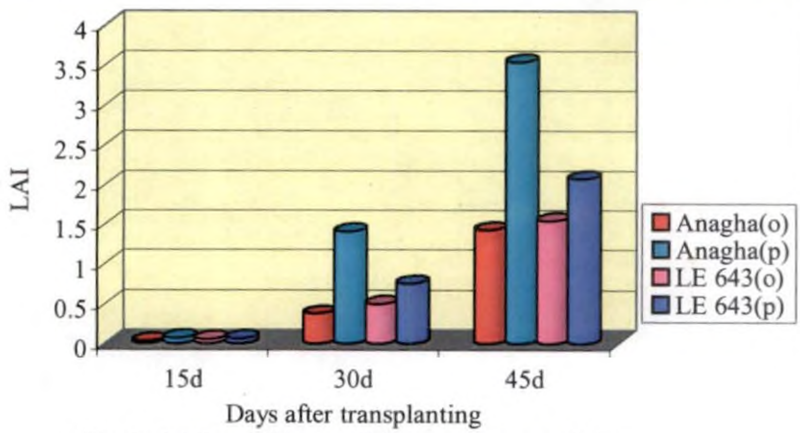

Fig 5. LAI as influenced by growing condition

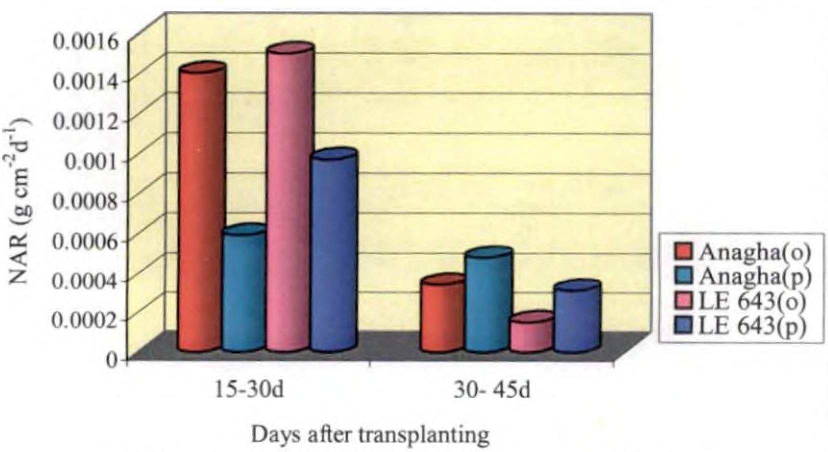

Fig 6. NAR as influenced by growing condition

response was noted with respect to growing condition. Highest mean LAI of 2.81 was computed for polyhouse crop. Anagha indicated a LAI of 0.033 at 15 DAT in open field. Corresponding values recorded at further stages were 0.38 and 1.43.

Leaf Area Index of variety LE 643 steadily increased over the period. At 15 DAT, LAI was 0.058 in open field. At later stages, 0.5 and 1.54 were obtained. In polyhouse, LE 643 showed maximum LAI of 2.07 at 45 DAT (Fig 5). At initial crop growth period, the values were computed as 0.07 and 0.76. Anagha in polyhouse gave highest LAI of 3.54 at 45 DAT. Corresponding values were 0.072 and 1.411 at initial stages. In general, polyhouse crop expressed higher LAI compared to open field crop.

4.2.3 Net Assimilation Rate (NAR)

Net Assimilation Rates calculated under different growing conditions are given in Table 7. As the crop growth advanced, NAR decreased under both conditions (Fig 6).

At first growth period, LE 643 had a NAR of 0.0015 g $cm^{-2}d^{-1}$ in open field whereas it was 0.00097 g $cm^{-2}d^{-1}$ in polyhouse. Corresponding values for Anagha were 0.0014 g $cm^{-2}d^{-1}$ and 0.00059 g $cm^{-2}d^{-1}$. At second interval, Anagha had NAR of 0.00034 g $cm^{-2}d^{-1}$ in open field and a slightly higher assimilation rate was obtained in polyhouse (0.00048 g $cm^{-2}d^{-1}$). LE 643 obtained NAR of 0.00031 $gcm^{-2}d^{-1}$ *in polyhouse* whereas lesser NAR of 0.00015 g $cm^{-2}d^{-1}$ was noticed in open field. Higher mean NAR (0.00039 $gcm^{-2}d^{-1}$) was computed in polyhouse during this period.

4.2.4 Crop Growth Rate (CGR)

Crop Growth Rate of the varieties were computed and given in table 8. Crop Growth Rate was highest at 30-45 DAT. At this stage, Anagha expressed higher CGR of 4.65 g $m^{-2}d^{-1}$ in polyhouse and 2.73 g $m^{-2}d^{-1}$ in open field.

Table 6. Leaf Area Index (LAI) as influenced by growing condition

Variety	15 DAT		30 DAT		45 DAT	
	Open field	Polyhouse	Open field	Polyhouse	Open field	Polyhouse
Anagha	0.033	0.072	0.38 (0.94)	1.41(1.37)	1.43(1.38)	3.54(1.98)
LE 643	0.058	0.067	0.50(0.99)	0.76(1.12)	1.54(1.42)	2.07(1.60)
Mean	0.046	0.07	0.44 (0.97)	1.08(1.24)*	1.49(1.39)	2.81 (1.79)
SE	0.0043		0.0589		0.1283	
CD (G)	0.0096		0.1330		0.2904	
CD (I)	0.0137		0.1883		NS	

Table 7. Net Assimilation Rate (NAR g $cm^{-2}day^{-1}$) as influenced by growing condition

Variety	15-30 DAT		30-45 DAT	
	Open field	Polyhouse	Open field	Polyhouse
Anagha	0.0014 (0.707)	0.00059(0.707)	0.00034	0.00048
LE 643	0.0015 (0.708)	0.00097(0.707)	0.00015	0.00031
Mean	0.00144 (0.708)	0.00078 (0.707)	0.000243	0.000392
SE	0.0005		0.00001	
CD (G)	NS		0.000032	
CD (I)	NS		NS	

G - Growing condition
I - Interaction between varieties and growing condition
* Values in parenthesis are transformed values

Indeterminate variety showed a growth rate of 4.06 g $m^{-2}d^{-1}$ in polyhouse and 3.31 g $m^{-2}d^{-1}$ in open field. Higher mean CGR was obtained by polyhouse crop (4.35 g $m^{-2}d^{-1}$) than open field crop (3.02 g $m^{-2}d^{-1}$).

In contrast to previous situation, polyhouse crop had lower CGR of 1.43 at 15-30 DAT. In open field, it was computed as 2.89 g $m^{-2}d^{-1}$. At initial stage, highest CGR was observed for LE 643 in open field (3.94 g $m^{-2}d^{-1}$). Anagha exhibited a CGR of 1.85 g $m^{-2}d^{-1}$. CGR was computed as 1.17 g $m^{-2}d^{-1}$ for Anagha and 1.69 g $m^{-2}d^{-1}$ for LE 643 in polyhouse (Fig 7).

4.3 REPRODUCTIVE CHARACTERS

4.3.1 Days to flower

The number of days taken for first flowering is presented in Table 9. Open field crop was earlier in first flowering, which took only 28.05 days after transplanting, compared to 31.08 days in polyhouse. The character showed significant difference between varieties and between growing conditions.

For both varieties, flowering was delayed in polyhouse (Fig 8). Anagha took 31.45 days in polyhouse compared to 29.65 days in open field. Corresponding values were 30.70 and 26.45 for the indeterminate variety.

4.3.2 Number of inflorescences

Observations recorded on this trait are presented in Table 10. Higher number of inflorescences was observed in polyhouse crop at all stages.

At 30 DAT, LE 643 produced maximum number of inflorescences (9.95) in polyhouse. Corresponding value was 7.99 in open field. At that stage, Anagha produced 8.77 and 5.26 respectively. Polyhouse crop had a higher mean value of 9.36 and in open field it was 6.63 (Fig. 9).

Table 8. Crop growth rate (g m^{-2} day^{-1} CGR) as influenced by growing condition

Variety	15-30 DAT		30-45 DAT	
	Open field	Polyhouse	Open field	Polyhouse
Anagha	1.848 (1.507)	1.165 (1.29)	2.727 (1.769)	4.645 (2.214)
LE 643	3.937 (2.096)	1.687 (1.473)	3.308 (1.934)*	4.062 (2.087)
Mean	2.892 (1.802)	1.426 (1.382)	3.017 (1.85)	4.35 (2.15)
SE	0.1121		0.2308	
CD (G)	0.2536		NS	
CD (I)	NS		NS	

Table 9. Days to flower and harvest as influenced by growing condition

Variety	Days to flower		Days to harvest	
	Open field	Polyhouse	Open field	Polyhouse
Anagha	29.65	31.45	65.88	67.0
LE 643	26.45	30.70	66.05	66.48
Mean	28.05	31.08	65.96	66.94
SE	0.5884		0.9123	
CD(G)	1.331		NS	
CD(I)	NS		NS	

G - Growing condition

I - Interaction between varieties and growing condition

* Values in parenthesis are transformed values

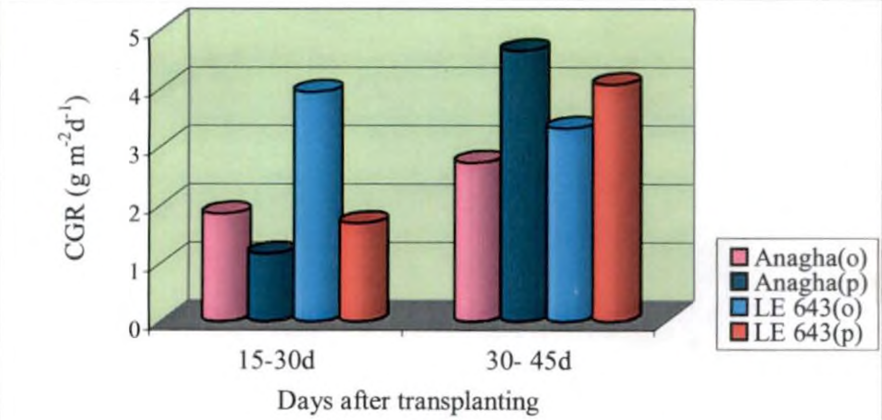

Fig 7. CGR as influenced by growing condition

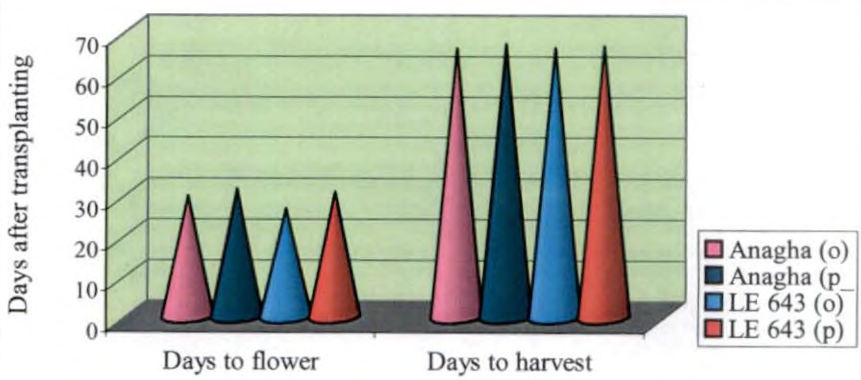

Fig 8. Earliness in flowering and harvesting as influenced by growing condition

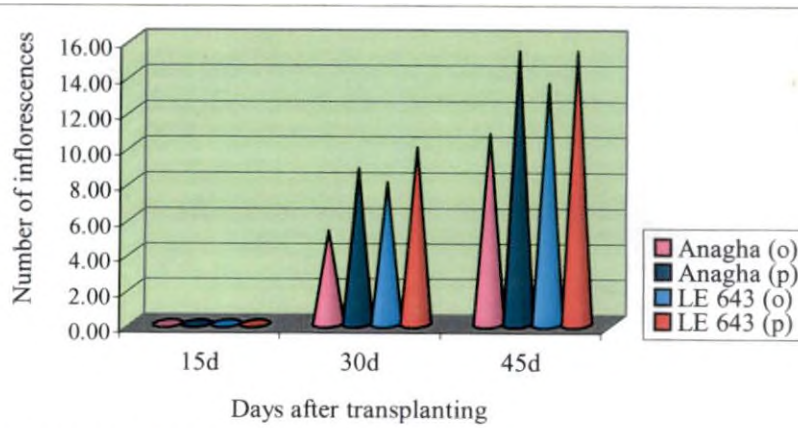

Fig 9. Number of inflorescences as influenced by growing condition

LE 643 had 15.35 inflorescences in polyhouse compared to 13.55 in open field at 45 DAT. At that stage, Anagha recorded a lower number of inflorescences of 10.73 in open field and 15.35 in polyhouse. Significant differential response under growing condition was noted for the character.

4.3.3 Days to first harvest

The observations on days to first harvest are presented in the Table 9. Crop under polyhouse took maximum number of days (66.94) for first harvest whereas open field crop was comparatively earlier for both varieties and took 65.96 days for first harvest. Anagha in open field was harvested at 65.88 days and it took 67 days in polyhouse. Corresponding values for LE 643 were 66.05 and 66.48 days (Fig. 8).

4.3.4. Fruit size

The fruit size was determined based on equatorial fruit diameter and is given in Table 11. Polyhouse crop expressed an average equatorial fruit diameter of 3.97cm, which was almost equal to that of open field (3.95cm). Anagha produced largest fruits with 4.06cm size in polyhouse followed by LE 643 (Plate 9) with 4.0cm in open field (Fig.10). Fruit size of Anagha in open field was measured as 3.9cm. LE 643 in polyhouse (Plate 10) had an equatorial fruit diameter of 3.87cm. Thus both varieties belonged to the category of small sized fruits irrespective of growing conditions.

4.3.5. Fruit weight

Data recorded on average single fruit weight is given in Table 11. Heaviest fruits were produced by polyhouse crop of Anagha (plate 12) and had maximum

Table 10. Number of inflorescences as influenced by growing condition

Variety	30 DAT		45 DAT	
	Open field	Polyhouse	Open field	Polyhouse
Anagha	5.26	8.77	10.73	15.35
LE 643	7.99	9.95	13.55	15.35
Mean	6.63	9.36	12.14	15.35
SE	1.0095		1.0468	
CD (G)	2.283		2.368	
CD (I)	NS		NS	

Table 11. Fruit size (cm) and fruit weight (g) as influenced by growing condition

Variety	Fruit size (cm)		Fruit weight (g)	
	Open field	Polyhouse	Open field	Polyhouse
Anagha	3.9	4.06	34.25	37.47
LE 643	4.00	3.87	31.33	29.54
Mean	3.95	3.97	32.79	33.51
SE	0.0760		2.3206	
CD (G)	NS		NS	
CD (I)	NS		NS	

G - Growing condition
I - Interaction between varieties and growing condition

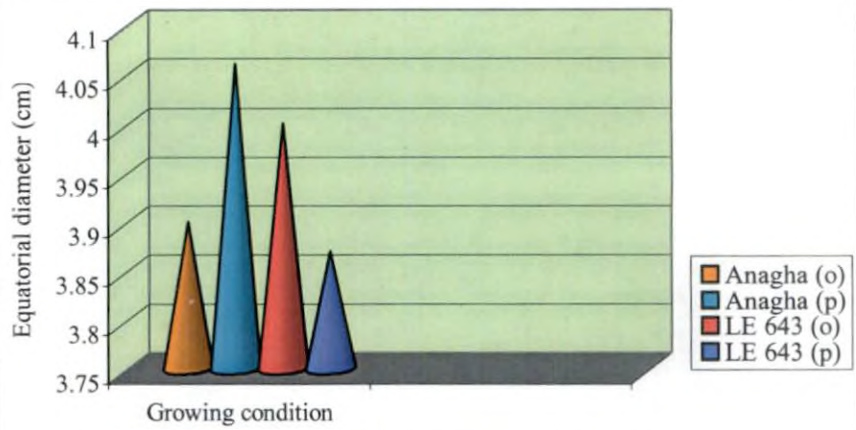

Fig 10. Fruit size as influenced by growing condition

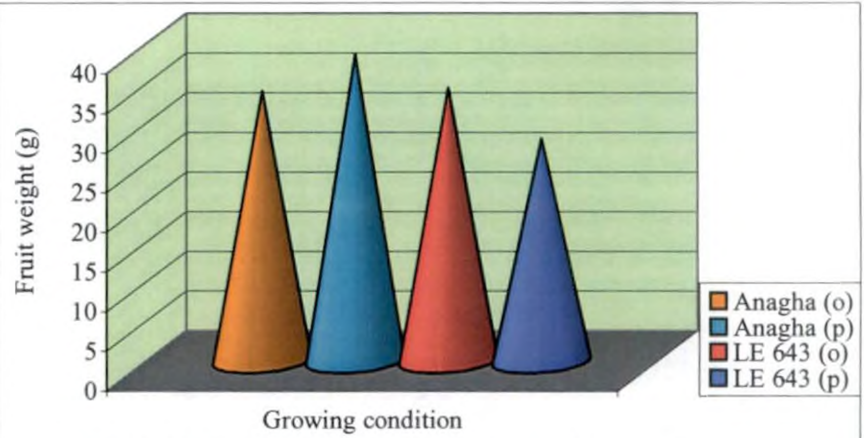

Fig 11. Fruit weight of tomato as influenced by growing condition

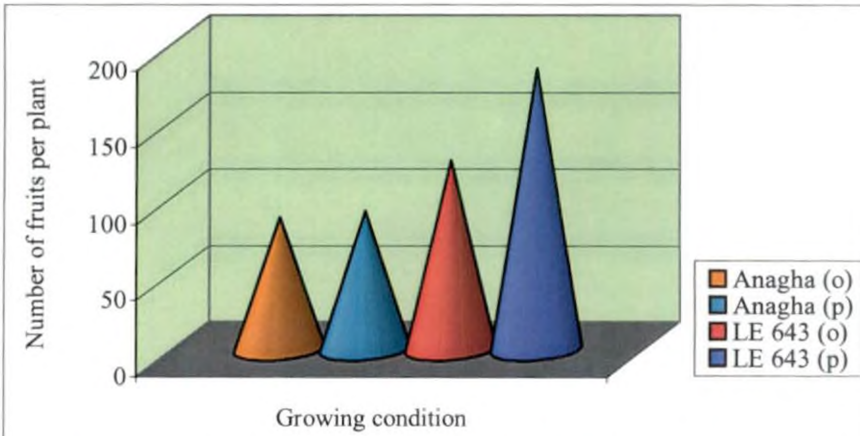

Fig 12. Number of fruits per plant as influenced by growing condition

fruit weight of 37.47g. In contrast to it, LE 643 under polyhouse gave lowest single fruit weight of 29.54g (Fig.11). Anagha (Plate 11) and LE 643 recorded 34.25g and 31.33g respectively in open field. On an average, polyhouse crop gave single fruit weight of 33.51g compared to 32.79g in open field.

4.3.6. Number of fruits per plant

Number of harvested fruits per plant for different varieties is given in Table 12. Polyhouse crop produced higher mean number of fruits and recorded 137.21. In open field, 105.37 fruits were harvested on an average.

In polyhouse, 90.85 fruits were harvested in Anagha (Fig.12). In open field, number of fruits was reduced and recorded as 86.84. A maximum of 183.57 fruits were picked in LE 643 in polyhouse whereas 123.90 fruits were harvested in open field.

4.3.7. Number of harvests

The data on number of harvests is presented in Table 12. Number of harvests was maximum in LE 643 in polyhouse (10.24). In contrast to that crop duration of Anagha in open field was extended with 8.94 harvests whereas in polyhouse it was 8.12. Open field crop of LE 643 was harvested 8.83 times (fig.13). There was no significant difference with respect to growing conditions. Poly house and open field crop recorded mean number of 9.18 and 8.88 harvests respectively.

4.3.8. Yield per plant

Yield of the varieties under different growing conditions are presented in Table 12. Higher productivity was shown by polyhouse crop and recorded 2.97 kg per plant. Open field crop gave a yield of 2.23 kg. Indeterminate LE 643 recorded highest yield of 3.59 kg in polyhouse followed by the same variety in open

Plate 9. Fruits of LE 643 in open field

Plate 10. Fruits of LE 643 in polyhouse

Plate 11.Fruits of Anagha in open field

Plate 12. Fruits of Anagha in polyhouse

Plate13. Cracked fruits of LE 643 in
in open field

Plate14. Spotted wilt incidence in
polyhouse crop

Table 12. Number of fruits per plant, Number of harvests per plant and yield per plant (Kg) as influenced by growing condition

Variety	Fruit number per plant		Number of harvests		Yield per plant (Kg)	
	Open field	Polyhouse	Open field	Polyhouse	Open field	Polyhouse
Anagha	86.84	90.85	8.94	8.12	1.98	2.34
LE 643	123.90	183.57	8.83	10.24	2.48	3.59
Mean	105.37	137.21	8.88	9.18	2.23	2.97
SE	19.14		0.6357		0.3934	
CD (G)	NS		NS		NS	
CD (I)	NS		NS		NS	

Table 13. Biotic and abiotic factors as influenced by growing condition

Variety	Cracking (%)	Mosaic incidence(%)	Spotted wilt incidence(%)
Anagha (O)	1.63	17.19	12.51
Anagha (P)	0	26.19	36.93
LE 643 (O)	7.88	28.57	12.51
LE 643 (P)	3.52	32.14	13.10

G - Growing condition
I - Interaction between varieties and growing condition
O - Open field
P - Polyhouse

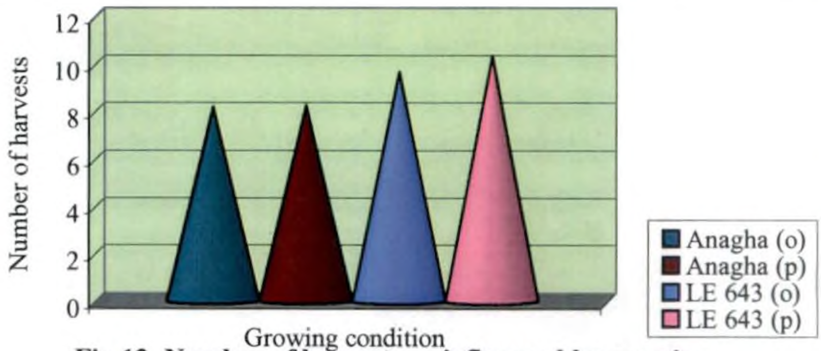

Fig 13. Number of harvests as influenced by growing condition

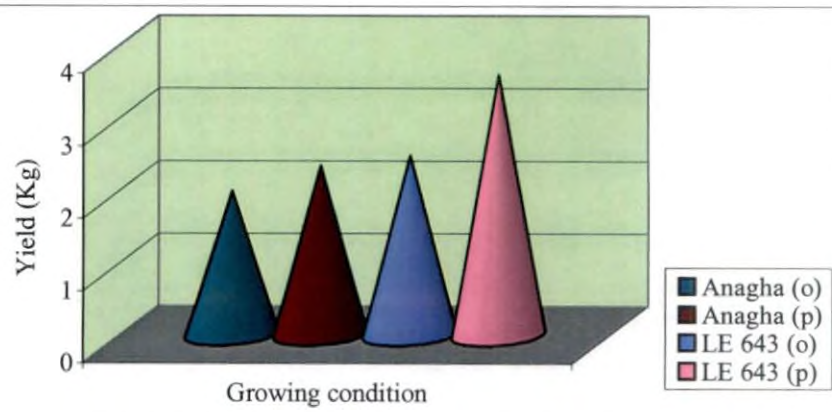

Fig 14. Yield per plant as influenced by growing condition

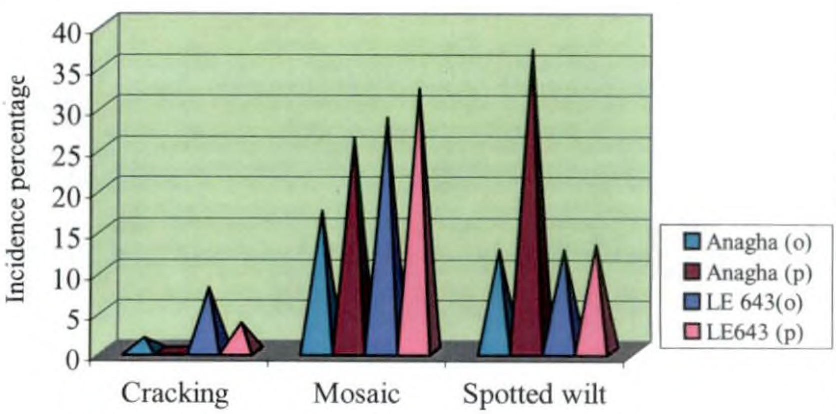

Fig 15. Biotic and abiotic factors as influenced by growing condition

condition (2.48 kg). Lowest per plant yield was given by Anagha in open condition which recorded 1.98 kg (Fig.14). In polyhouse, the variety gave higher yield of 2.34 kg. There was no significant difference in varieties with respect to yield in different growing conditions.

4.4 CROP WEATHER CORRELATION STUDIES

4.4.1 Simple correlation of plant characters with weather parameters

Simple correlation between important plant characters viz, plant height, number of branches, internodal length, number of inflorescences, days to first flower and days to harvest with weather parameters (Table 20 and 21) for different growing conditions were computed and correlation coefficients are presented in table 14 and table15.

Correlation between plant height and maximum temperature was found to be significant irrespective of variety and growing condition and was positive. The same result holds good for number of branches, internodal length and number of inflorescences. Days to flower showed negative significant correlation with maximum temperature in case of Anagha in polyhouse condition (r = -0.7573) where as it was positive significant correlation under open condition (r = 0.8183).

Days to flower showed significant negative correlation with minimum temperature (r = -0.9542) for Anagha in polyhouse but positive significant correlation was noted with days to first harvest for Anagha in polyhouse (r = 0.6586). LE 643 in polyhouse showed positive significant correlation (r= 0.8875) between light intensity and days to flower. Significant negative correlation was noted in case of days to first harvest with light for Anagha in open field (r= -0.8445) and LE 643 in (r=-9358). But significant positive correlation was observed for Anagha in polyhouse (r = 0.7489).

Table 14. Simple correlation of plant characters of Anagha with weather parameters

Plant characters	Min Temperature		Max Temperature		Light intensity		Rainfall		RH(morning)		RH(noon)	
	Open field	Poly house	Open field	Poly house	Open field	Poly house	Open field	Poly house	Open field	Poly house	Open field	Poly house
Plant height	0.0977	-0.0077	0.7383**	0.8335**	0.5087	0.4259	-0.5916*	-0.5938*	0.5388	0.8782**	-0.0030	0.4823
No of Branches	-0.0004	-0.0508	0.7476**	0.8102**	0.4974	0.3859	-0.5930*	-0.5705	0.5159	0.8721**	-0.0893	0.5052
Internodal length	0.0421	-0.1314	0.6963*	0.8290**	0.4304	0.4361	-0.5714	-0.5209	0.4716	0.9011**	-0.0639	0.4740
No of inflorescence	0.1230	0.0616	0.6854*	0.8521**	0.4622	0.4535	-0.5627	-0.6402*	0.4878	0.8682**	-0.0083	0.4261
Days to flower	0.4297	-0.9542**	0.8183**	-0.7573**	0.3429	-0.2335	-0.7156**	0.9974**	0.5135	-0.6434*	0.2388	0.3234
Days to harvest	0.2423	0.6586*	-0.9025**	0.9167**	-0.8445**	0.7489**	0.5203	-0.7078*	-0.8085**	0.8563**	-0.2535	-0.8761**

Table 15. Simple correlation of plant characters of LE 643 with weather parameters

Plant characters	Min Temperature		Max Temperature		Light intensity		Rainfall		RH(morning)		RH(noon)	
	Open field	Poly house	Open field	Poly house	Open field	Poly house	Open field	Poly house	Open field	Poly house	Open field	Poly house
Plant height	0.1265	0.0329	0.7494**	0.8094**	0.4687	0.4393	-0.6369*	-0.5792*	0.4962	0.8403 **	-0.0539	0.4495
No of Branches	0.0688	-0.1080	0.7112**	0.8027**	0.4665	0.3480	-0.5673	-0.5605	0.5221	0.8803**	0.0033	0.5290
Internodal length	0.0519	-0.1434	0.6114*	0.7257**	0.4349	0.2127	-0.4433	-0.5454	0.5058	0.8259**	0.0155	0.5861*
No of inflorescence	0.1431	0.0821	0.7603**	0.8885**	0.4911	0.4173	-0.6541*	-0.7403**	0.4972	0.8854**	-0.0409	0.3345
Days to flower	0.4297	-0.4292	0.8183**	0.4730	0.3429	0.8875**	-0.7156**	0.2807	0.5135	0.6057*	0.2388	-0.7196**
Days to harvest	-0.6820*	-0.2493	-0.5880*	-0.8205**	-0.0465	-0.9358**	0.6173*	0.3225	-0.3233	-0.8302**	-0.2824	0.9982**

* Significant at 5% level
** Significant at 1% level

Plant height had significant negative correlation with rainfall in all cases. Branching and rainfall showed a negative significant correlation (r= -0.5930) for Anagha in open field. LE 643 in open field (r= -0.6541) and polyhouse (r = -0.7403) and Anagha in polyhouse (r= -6402) had negative significant correlation between number of inflorescence and rainfall. Days to flower exhibited significant negative correlation with rainfall in open condition for both varieties whereas a positive significant correlation was observed for Anagha in polyhouse (r= 0.9974). Anagha in polyhouse had significant negative correlation between days to harvest and rainfall (r= -0.7078) whereas a positive significant correlation was noticed in case of LE 643 in open field (r=0.6173).

Relative humidity at morning positively influenced plant height, number of branches, internodal length, and number of inflorescence in polyhouse irrespective of variety. Relative humidity at morning showed significant positive correlation (r= 0.6057) with days to flower but a significant negative correlation with days to harvest (r= -0.8302) for LE 643 in polyhouse and reverse situation was noted in case of polyhouse Anagha. Anagha in open field exhibited significant negative correlation in case of days to first harvest (r= -0.8085) but a positive one was noted in polyhouse (r= 0.8562).

Relative humidity at afternoon had a significant positive correlation for LE 643 in polyhouse in case of internodal length (r= 0.5861) and a significant negative correlation (r= -0.7196) with days to flower. Positive and significant correlation was obtained between RH at afternoon and days to harvest for LE 643 in polyhouse (r= 0.9982) and a significant negative correlation was observed for Anagha in polyhouse (r= -0.8761).

4.4.2 Canonical correlation of plant characters with weather parameters

The simple correlations give relationship between the plant characters and weather parameters pair wise only. The plant growth is depicted by a multiplicity of parameters and is directly influenced by weather parameters. To exploit the multivariate relationship between plant characters and weather parameters, canonical correlation analysis was carried out. Plant characters viz, plant height, number of branches, internodal length, number of inflorescences, days to first flower and days to first harvest and weather parameters such as minimum and maximum temperatures, light intensity, rainfall, RH at morning and afternoon were considered for the analysis. The canonical correlation was computed irrespective of variety. The loadings of the variables for plant characters as well as weather parameters and canonical correlation coefficients are given in table 16, 17 and 18.

In the open condition, the first canonical correlation was 0.9498 but explained only 40.87 % variability whereas second canonical correlation was 0.6670 with a subsequent explanation of 28.7 % variability. The cumulative variability explained by two canonical correlations was 69.57 %. The canonical correlation of the same plant characters with weather parameters under polyhouse were computed including and also excluding influence of rainfall. The first canonical correlation when influence of rainfall was not included was 0.8733 at 46.35 % variability and 0.5508 at 29.24 % variability with cumulative variability explained totalling into 75.59 %. The corresponding canonical correlations when influence of rainfall was included were 0.8824 (39.7 % variability) and 0.5514 (24.81 % variability) with the cumulative variability explained being 64.51 %.

4.4.3 Partial correlation of yield with weather parameters

Partial correlation of crop yield with weather parameters were computed to measure the exact relationship after averaging out the effect of the remaining parameters. Results of partial correlation study are presented in Table 19.

Table 16. Canonical correlation of plant characters as influenced by growing condition

Growing condition	Canonical correlation		Variabilityexplained		Cumulative variability
	(1)	(2)	(1)	(2)	
Open field	0.9498	0.6670	40.87	28.70	69.57
Polyhouse *	0.8733	0.5508	46.35	29.24	75.59
Polyhouse**	0.8824	0.5514	39.70	24.81	64.51

Table 17. Loadings of plant characters in canonical correlation

Loadings / Plant characters	First			Second		
	Open field	Polyhouse *	Polyhouse **	Open field	Polyhouse *	Polyhouse **
Plant height	-0.0131	0.0328	0.0324	0.0305	-0.0161	0.0165
Number of branches	0.03478	-0.1051	-0.1035	-0.0766	-0.0889	0.0864
Internodal length	-0.0123	0.1476	0.0917	-0.6928	0.4275	-0.3806
Number of inflorescence	0.0237	-0.0178	-0.0121	0.0262	0.0582	-0.0625
Days to first flower	-0.0073	0.3633	0.3591	0.0574	-0.0518	0.0567
Days to first harvest	-0.0753	0.0464	0.0331	-0.0307	-0.0970	0.1053

* Effect of rainfall is not considered

** Effect of rainfall is considered

Table18. Loadings of weather parameters in canonical correlation

Loadings / Weather parameters	First			Second		
	Open field	Polyhouse *	Polyhouse **	Open field	Polyhouse *	Polyhouse **
Minimum temperature	-0.3977	-0.0482	0.0154	-0.3031	0.0930	-0.1193
Maximum temperature	0.4171	-0.1314	0.6761	0.3762	-0.2192	-0.1157
Light intensity	0.0014	0.0027	-0.0059	0.0020	0.0012	0.0024
Rainfall	-0.0461	-	0.3223	0.0539	-	-0.1317
RH(morn)	-0.0814	0.0205	-0.1128	-0.0752	0.0419	0.0136
RH(noon)	0.0798	0.0107	0.0295	0.0695	-0.0248	0.0171

* Effect of rainfall is not considered

** Effect of rainfall is considered

Crop yield of Anagha was not showing any correlation with the weather parameters under consideration in open field except light which was 0.3978 at 28.9 % probability level of significance. Under polyhouse Anagha showed positive correlation of 0.5105 at 16 % probability level of significance with minimum temperature . The correlation with remaining parameters were not significant at all.

The same results as that of Anagha hold good for the crop yield of LE 643 under open condition with the additional fact that even with light intensity, no correlation could be traced out. Crop yield of Anagha under polyhouse showed a positive correlation of 0.4148 at 26.7% probability level of significance with maximum temperature whereas the crop yield of LE 643 showed a positive correlation of 0.7979 at 1% probability level of significance with maximum temperature, 0.4465 at 22.8% probability level of significance with rainfall and 0.5409 at 13.3% significance level with RH at after noon. A negative correlation of 0.4899 at 18.1% probability level of significance with light intensity was observed.

When the partial correlation of all the weather parameters excluding influence of rainfall was computed, for both varieties under polyhouse, the same mode of correlation but with a slightly increased probability level of significance was noticed.

4.5 Biotic and abiotic factors

Cracking was observed more in open field irrespective of variety. LE 643 in open field exhibited 7.88 percentage cracking (Plate 13) whereas a lesser cracking (3.52%) was observed for the crop in polyhouse. Anagha in open field showed cracking to a small extent and computed as 1.63 percentage. No fruit cracking was noticed in polyhouse crop of Anagha

Table 19. Partial correlation of yield with weather parameters

Growing condition	Minimum Temperature		Maximum Temperature		Light Intensity		Rainfall		RH (morning)		RH (noon)	
	Correl ation	Prob Level (%)	Correl ation	Prob level(%)	Correl ation	Prob level(%)	Correl ation	Prob level(%)	Correl ation	Prob level(%)	Correl ation	Prob level(%)
Anagha (O)	-0.141	71.7	0.0921	81.4	0.3978	28.9	-0.0086	98.3	-0.2382	53.7	-0.1518	69.7
LE 643 (O)	0.0147	97	0.2504	51.6	0.2319	54.8	0.2302	55.1	-0.0375	92.4	-0.2297	55.2
Anagha (P)*	0.5105	16	0.4148	26.7	0.0782	84.2	0.2807	46.4	0.0096	98.1	0.0640	87
LE 643 (P)*	0.1220	75.5	0.7979	1	-0.4889	18.1	0.4465	22.8	0.2231	56.4	0.5409	13.3
Anagha(P)**	0.4532	18.8	0.3184	37	0.1663	64.6	-	-	0.0052	98.9	0.1967	58.6
LE 643 (P)**	-0.0274	94	0.7570	1.1	-0.3595	30.8	-	-	0.1946	59	0.6463	4.3

O - Open field
P - Polyhouse

* Effect of rainfall is considered

** Effect of rainfall is not considered

Table 20. Weather data during 2005 October-2006 February in open field

Standard week	Minimum temperature(°C)	Maximum temperature(°C)	RH (morning) (%)	RH(noon) (%)	Light (lux)	Rainfall (mm)
40	24.6	32.5	63.8	59.4	461.2	34.6
41	23.0	33.0	80.2	61.1.	768.8	1.2
42	24.0	34.5	58.7	38.5	569.6	4.1
43	24.0	36.0	89.6	62.1	813.7	6.4
44	23.0	36.0	89.5	53.2	752.0	0
45	24.8	34.5	84.4	63.6	773.4	0
46	23.0	33.8	91.0	72.0	477.3	0.8
47	20.5	32.0	91.5	74.5	683.8	2.4
48	23.5	33.8	80.5	69.8	859.2	0
49	24.9	33.8	86.5	59.7	812.0	0
50	22.3	36.2	85.6	49.8	870.6	0
51	22.5	35.0	85.2	44.2	845.5	.0
52	22.5	34.9	89.5	68.9	955.5	0
1	24.0	35.5	86.7	71.0	906.8	0
2	22.0	35.0	89.3	56.9	936.0	0
3	24.8	35.0	90.6	48.5	946.7	0
4	20.8	35.5	91.0	64.4	747.4	0
5	24.0	36.6	89.7	62.2	517.5	0
6	22.0	35.0	88.0	61.0	760.3	0

Table 21. Weather data during 2005 October-2006 February in polyhouse

Standard week	Minimum temperature(°C)	Maximum temperature(°C)	RH (morning) (%)	RH(noon) (%)	Light (lux)
40	22.2	34.2	51.5	48	281.2
41	21.3	37.5	59.6	39.4	467.5
42	23.5	39.8	62.2	38.4	422
43	23	41.6	69.8	41	463.2
44	20.8	42.5	82.1	51	404.5
45	22.5	41	73.6	54.7	468.6
46	21	41.5	78.7	33.8	289.2
47	19	42.8	76.3	37.3	443.2
48	21.5	41.5	75.8	29.8	572.3
49	21.5	42	73.7	35.7	648.7
50	21	44	60.6	24.2	623.6
51	16.1	43.5	61	20	693.8
52	19.2	41.5	67.5	29.4	569.3
1	22.5	41	79.6	21.7	545
2	22.8	41.8	54.2	21	596.5
3	24.5	43.2	77.8	23	567.2
4	23.5	45	73.7	33	466.3
5	23	43.2	64.2	43.2	339.3
6	20	42	62.8	33.8	473.5

No major pest was noticed during the entire cropping period. However fruit borer attack was noticed during the early stage which was immediately controlled. Nevertheless diseases like spotted wilt, leaf curl, cercospora leaf spot and mosaic incidence were noticed. All the diseases were promptly controlled at the early stages except spotted wilt and mosaic. The incidences were very high and were uncontrollable at later stages.

The percentage incidence of the mosaic and spotted wilt were calculated and is presented in Table 13. Minimum incidence of the mosaic disease was noticed in open field. Anagha showed 17.19 per cent incidence whereas LE 643 was more affected with it and incidence was calculated as 28.57 per cent in open field. Incidence percentages were 26.19 and 32.14 respectively in polyhouse. Spotted wilt (Plate 14) also showed maximum incidence for Anagha in polyhouse and was calculated as 36.90 per cent and in open field it was 12.5 per cent. LE 643 showed higher incidence in polyhouse (13.10 %) compared to crop in openfield (12.5 %) (Fig.15).

Discussion

5. DISCUSSION

Climate decides crop selection while weather decides crop production and productivity. Crop production depends on factors such as genotype, soil, weather, technology and the farmer. Any weak link in the chain of factors will decide the final crop output (Rao *et al.*, 2002). Greenhouse technology has been found to be an appropriate intervention in the development of horticulture in India. This technology is based on the principle that productivity of a crop is influenced not only by its heredity but also by the microclimate around it. The components of microclimate are light, temperature, air composition and nature of growing medium. Under open field condition, it is not possible to control any of these factors (Choudhary and Shukla, 2004).

The plant response to specific environmental parameters is related to physiological processes, which in turn is related to yield variation. If the required environment is controlled properly, crop can be raised with good quality and with increase in yield for specific market schedule.

The present study entitled "production physiology of polyhouse tomato (*Lycopersicon esculentum* Mill.)" was attempted to analyse the physiological reasons attributing to yield under protected and open condition and also to study their correlation with different weather parameters. Results of the study are presented under the following heads.

5.1 Influence of growing condition on vegetative characters
5.2 Influence of growing condition on growth parameters
5.3 Influence of growing condition on reproductive characters
5.4 Influence of growing condition on biotic and abiotic factors
5.5 Crop weather correlation

5.1 INFLUENCE OF GROWING CONDITION ON VEGETATIVE CHARACTERS

Tomato production is highly influenced by environmental factors particularly temperature, light and CO_2. Day and night temperatures are important for tomato growth. Day temperature of 28°C and night temperature of 18°C is ideal (Hebbar, 2004).

From Table 1, it is evident that polyhouse crop in general had a vigorous growth in terms of plant height at 15 DAT and the same mode of incremental height was achieved at 30 DAT and 45 DAT. The crop in open field had a lesser plant height upto 45 DAT and had an extended phase of growth even after 45 DAT. Day temperature was comparatively higher in polyhouse (34.2 - 43.5°C) than open field (32.0-36.6 °C) throughout the crop growth. Plant height is a function of number of nodes and length of each internode and both are strongly influenced by temperature. Light intensity was 25-40 % lesser in polyhouse, which has an influential role in plant height and growth. Similar results were obtained by Lara *et al.* (1999). Schoch (1972) explained that shading the plants increased cell division and cell expansion. Auxin concentration may increase under shade condition and results in increased plant height because of apical dominance. Apical dominance along with increased rate of cell division and cell enlargement greatly influence plant height. At 30 DAT, light intensity was increased (404.5 –693.6 lux) and is attributed to the slight reduction in plant height in polyhouse compared to open field crop. Gradual increase in air temperature influenced plant growth at 30 DAT. Arora *et al* (1982) found similar results that temperature negatively influenced plant height. Calvert (1965) found that the rate of development of the apical portion of plant at high temperature is slowed down because more assimilates are diverted towards the leaves than the growing point. Hussey (1963) also reported that the apical shoot elongation is delayed at high temperature.

Branching was comparatively higher in open field condition. Reduced light intensity observed in polyhouse might have an effect on number of branches. Crop in open field showed shorter internodes up to 45 DAT. This might have encouraged the production of more branches. Higher auxin concentration which may occur under low light intensity might have increased internodal length in polyhouse. Higher RH (38.5-91.5%) positively influenced the number of branches in open field. Shinde *et al.* (1999) reported that micro irrigation with sugarcane trash increased RH level and increased plant height and number of branches were noticed.

5.2 INFLUENCE OF GROWING CONDITION ON GROWTH PARAMETERS

Growth parameters like RGR, NAR, LAI and CGR were calculated and analysed statistically. Bright sunshine and temperature have positive effect on photosynthesis and thus increase total biomass production (Tesar, 1984). This could be the reason for higher RGR and NAR during first interval (15-30 DAT) in open field. Net Assimilation Rate and RGR showed decline over the period and was higher in polyhouse during second interval (30-45 DAT). Goudriaan and Monteith (1990) obtained similar results and concluded that mutual shading of leaves begin within few weeks of emergence and is the major reason for this decline. Light intensity positively influences NAR at seedling stage (Bakker *et al.*, 1995). Bakker (1991) reported a small but significant increase in RGR in response to an increase in day time humidity for tomato seedlings. In agreement with this, tomato in open field exhibited relatively higher growth rate at seedling stage.

The rate of development of the apical portion of the plant at high temperature is slowed down because more of assimilates are diverted towards the leaves than the growing point (Calvert, 1965) and this process increases the number of leaves and RGR at the early stage. Mean daily temperature has been found to affect the growth rate of greenhouse tomato (Seginer *et al.*, 1994).

Changes in RGR during the seedling stage is mainly caused by changes in Leaf Area Ratio (LAR) and not by changes in NAR (Heuvelink, 1989).

Leaf Area Index (LAI) and CGR showed increase during the crop period. Increase in CGR observed during the second interval under high day temperature regime in polyhouse may be the result of net photosynthesis which in turn is due to increase in LAI. Friend and Helson (1976) reported similar results agreeing to it. As LAI increases, NAR decreases though CGR is increasing during the same period. The decrease in NAR result from progressive increase in mutual shading of leaves (Tesar, 1984).

Watson (1947) and Boardman (1977) reported that CGR would increase as LAI increased to an optimal level where canopy intercepted 95% solar radiation. As shading has an effect on reducing NAR, low light intensity might have resulted in lower RGR and NAR at initial stages in polyhouse. Further, increase in temperature and light intensity could have increased biomass production and finally RGR and NAR in polyhouse compared to open field. Heuvelink and Dorais (2005) suggested that crop growth may be increased by a higher temperature in the long term, because increased temperature may increase specific leaf area and thus leaf area development resulting in higher future light interception.

5.3. INFLUENCE OF GROWING CONDITION ON REPRODUCTIVE CHARACTERS

5.3.1 **Earliness in flowering and harvesting**

Earliness in flowering and harvesting is an indication of early transformation to reproductive phase. Days to first flower and first harvest are considered as indicators of earliness. In the present study, open field crop was early for flowering (28.05 days) and harvesting (65.96 days). Correlation study *shows that incessant rainfall (0.8 - 34.6mm) decreased days to flower for the crop* in open field indicated by negative correlation. The stress factors of the weather led to comparatively early flowering of crop.

Ho (1996) reasoned that under low light conditions, initiation of first inflorescence was delayed as more leaves were initiated prior to the inflorescence and reduced flower development and flower abortion were observed. This can be found in agreement with the delayed flowering observed in polyhouse. The normal temperature for flower initiation and anthesis is from 20°C to 25°C for tomato. *An increase in temperature from the normal (24°C day and 18°C night)* accelerates the production of leaves before the initiation of the first inflorescence (Kalloo, 1986). Early flowering is influenced by number of leaves produced up to the first inflorescence, which in turn is associated with high temperature (Lawrence, 1953).

The start of flower initiation favoured by low temperature is associated with the development of the apex (Hussey, 1963). In varieties like Potentato and Potolla, arrested flower development has been noticed at high temperature and low light intensity (Lake, 1967). Lower night temperature during different growth stages delayed fruit development and maturity in polyhouse. Similar results were reported by Longueness (1978). Nashath (2005) observed that tomato raised in rain shelter took maximum number of days to maturity compared to open field and agrees with the above observation.

Reduction in duration of fruit growth might also be expected if the peroxidase activity responsible for growth termination was increased at higher temperature (Thompson *et al.*, 1998). Higher RH, relatively lower temperature and bright sunshine might have encouraged faster fruit ripening in open field. Early fruit production is more remunerative which is associated with early flowering (Kalloo, 1986).

5.3.2 Number of inflorescences

More number of inflorescences was seen in polyhouse crop compared to open field at all stages. Heuvelink and Dorais (2005) found that flowering rate increases almost linearly with temperature. Lower night temperature (16.1 – 24.5°C) prevailed in polyhouse throughout the growth period. Ho (1996) reported that low night temperature could induce the seedling to produce a higher flower number. Anbarasan (2002) observed that maximum number of inflorescences was produced in tomato under polyhouse condition. Deepa and Abu (1996) reported similar results.

5.3.3 Fruit characters and yield

There was no significant difference with respect to fruit characters. Still, slight increase was noted in case of fruit weight in polyhouse crop. High temperature favours the distribution of assimilates to fruit at the expense of vegetative growth (Dekoning, 1989). High temperature inside polyhouse increases sink strength and photo assimilate import into fruit which might have resulted in comparatively higher fruit weight. Ho and Hewitt (1986) reported similar results. This increase in fruit mass results from a higher average growth rate of individuals (Heuvelink and Dorais, 2005). De koning (1994) found that dry matter content of harvest ripe fruit increases with temperature. Increasing ambient temperature by 1°C increased fruit dry matter content by 0.07 per cent (De koning, 1992). Adams (1990) found that restriction in water supply increase K content in tomato plants under water stress condition. Smitha (2002) found that mild shade is favourable for increase in vitamin C in tomato.

Polyhouse crop produced maximum number of fruits per plant. There is a marked influence of temperature on the initiation of flowers, the number of flowers per inflorescence and the total number of flowers per plant, which are the major components of the number of fruits and yield (Kalloo, 1986). Temperature affects floral initiation, floral development, fruit set and fruit growth simultaneously and its effect is closely associated with light conditions (Heuvelink and Dorais 2005).

The size of inflorescence depends on night temperature. The warmer the night, the smaller is the size of inflorescence (Went, 1945). Size of inflorescence refers to number of flowers in each inflorescence. Higher the size of the inflorescences, higher will be the number of flowers and hence the number of fruits. Lewis (1953) stated that branching of inflorescence in tomato was a variable character that is found physiologically with the number of flowers. He opinioned that temperature and light are the most important factors affecting the inflorescence size. Thus higher number of inflorescences resulted in more number of fruits in polyhouse, which in turn resulted in increased number of harvests and yield in polyhouse.

In greenhouse practice, temperature seems to be the most suitable variable to control biomass partitioning as sink strength of individual fruits was immediately affected by temperature. High temperature enhances fruit growth at the expense of vegetative growth. At high temperature, the rate of plant development (increase in new leaves and trusses) is higher. Therefore growing young plants at high temperature will increase partitioning into the fruits as it increases the number of fruits in the plant. The strong assimilate demand by the growing fruits at higher temperature not only reduced leaf growth but also delayed growth of newly set fruits. As a consequence, after some time total sink strength of the fruits is low and then plant recovers vegetatively and healthy flowers are developed. Subsequently these flowers form strong sink, resulting in the onset of second cycle of strong fruit growth. This leads to a more or less pronounced alternation of fruit growth and vegetative growth (Heuvelink and Dorais, 2005). Extended crop duration in terms of number of harvests and number of fruits per plant and total yield found in polyhouse in the present study can be attributed to this.

Number of harvests was greatly influenced by growing conditions. Lower number of harvests was noticed in open field. Polyhouse is protected from harmful solar radiation by the covering with UV stabilized sheet. But in the open field, harmful solar radiation induces chlorophyllase and other destructive enzyme activity leading to degradation of chlorophyll. So, the entire production activity gets affected. This may lead to early ending of the crop and reduced number of harvests and yield under open field condition. This is in accordance with the findings of Vidalie *et al.* (1985).

Night temperature recorded was higher in open field (20.8-24.8 °C) through out the growth period. Plant could set fruit abundantly when the night temperature was between 15°C and 20°C and the day temperature at about 25°C (Went, 1944). Night temperature is more important than day temperature. According to Learner and Wittwer (1953), 21°C night temperature is the best for fruit set and yield of immature fruit in tomato. Thus lower night temperature (16.1°C - 24.5°C) prevailed during the period in polyhouse should have facilitated higher fruit set and thereby better yield.

Excess solar radiation has a role in reduction of yield. If the irradiation is high, the leaf temperature may increase and leaf temperature above 35°C could irreversibly damage the photosynthetic machinery (Bhatt, 2004). Lower yield noted in the open field can be attributed to this. Thus congenial weather conditions inside polyhouse allowed production of inflorescences even at later stages of growth compared to open field.

Even though not significant, yield was higher in polyhouse. Higher day and night humidity were recorded in open field. Bakker (1990) reported that in tomato, final yield was reduced by high humidity at night. Yield reduction between 18% and 21% under high humidity have been observed compared to lower humidity. Such yield reduction is probably related to a diminution of leaf due to calcium deficiency in the foliage (Holder and Cockshull, 1988) and reduced fruit growth rate (Bakker, 1990). There is also a reduction in the ovule fertilization rate due to more difficult release of pollen (Heuvelink and Dorais, 2005). Rain shelter cultivation of tomato at Plastic Culture Development Centre, Thavanur recorded a yield of 5 kg per m^2 where as it was only 1.3 kg per m^2 in open condition (KAU, 1999). Similarly, Indira *et al.* (2004) reported higher tomato yield in rain shelter.

Temperature plays an important role in the growth and development of plants (Rajendar,1985). Temperature influenced the rate of photosynthesis, respiration and other metabolic processes, which in turn influenced the yield, quality of the product and timing of crop maturity. Night temperature was lower in polyhouse. Calvert and Slack (1980) stated that increase in fruit yield was noticed when night temperature was lowered. The increased night temperature and night humidity could have resulted in lower fruit yield under open field condition. Saimbi and Gill (1988) noted that higher temperature prevailed during the season increased tomato yield. Polyhouse modify the environment for crop growth and ultimately facilitates a better yield. Incessant rainfall caused a reduction in crop yield as indicated by partial correlation study. The variation in performance of tomato under different situations is due to climatic variation prevailed in the locality as reported by Muthukrishnan *et al.* (1992).

Scholberg *et al.* (2000) found that lower LAI values would reduce light interception and increase yield losses due to sunburn. Leaf area index was found higher in crop raised in polyhouse at all stages. Heuvelink *et al.* (2005) reported that yield of tomato increased up to a LAI of four. Higher LAI contributed to higher photosynthesis and biomass production (Heuvelink and Dorais, 2005) and which in turn led to higher yield. Higher number of inflorescence and fruits per plant, higher number of harvests and higher fruit weight as a whole contributed to greater yield in polyhouse.

5.4 INFLUENCE OF GROWING CONDITION ON BIOTIC AND ABIOTIC FACTORS

Incidence of diseases such as mosaic and spotted wilt were more under polyhouse condition. Similar results were reported by Anbarasan (2002). Higher temperature and favourable microclimate favoured mosaic disease in polyhouse. Disease will spread faster once there is an incidence inside the polyhouse. High temperature favours white fly population, the vector of the virus disease (Rangaswamy and Mahadevan, 1999). Open sides of polyhouse encouraged easy entry of vector. It could have been reduced if nylon mesh was provided at all sides. Mosaic disease highly affected the indeterminate variety. But spotted wilt incidence was less severe in this. Traces of rainfall received might have reduced the building up of vector population in open field.

Cracking percentage was higher in open field. Anagha is a crack resistant variety even then, it exhibited the disorder slightly in open field. Rainfall received after a dry period might have encouraged cracking in open field. LE 643 had expressed higher cracking percentage in open field. Fruits produced under low humidity are firmer, juicy, less mealy in taste and had less physiological disorder such as gold speck and cracking than fruits produced under high humidity (Anbarasan, 2002). Thus lower RH prevailed in polyhouse reduced the severity of cracking in fruits. Dorais and Papadopoulose (2001) suggested that high humidity conditions cause a decrease in nutrient uptake (Ca) and an increase in root pressure and generally favours fruit cracking. Skin blemishes such as bruises, scorch marks, cuts and cracks reduce the appearance value in vegetables. Nashath (2005) found that tomato raised under rain shelter was excellent in appearance than that of open field crop. She also reported that moisture, fibre, protein, starch, calcium, iron, phosphorus, potassium, sodium and vitamin C were higher in fruits harvested from rain shelter. Genotypic difference in composition, skin anatomy and cell morphology are related to tomato fruit cracking (Dorais *et al.*, 2004).

5.5 CROP WEATHER CORRELATION

Simple correlation study between weather parameters and plant characters shows that maximum temperature had significant positive effect on plant height, number of branches, internodal length and number of inflorescence for both varieties irrespective of growing condition. According to Ponnuswamy and Muthukrishnan (1981) and Shonnard (1991), maximum temperature has positive influence on plant growth. Low RH and higher temperature might have contributed to better vegetative growth in polyhouse. Ajithkumar (1999) and Singh and Tripathy (1995) reported similar results. But intercepting rainfall at the critical stages of growth lessened the crop growth in open field as justified by the negative correlation. Even in polyhouse, rainfall bear a significant impact over the plant height and number of inflorescences. But its influence was much reduced as the polyhouse structure acted as a rain shelter.

Positive correlation of RH in the morning was noticed with plant growth in polyhouse for both varieties in terms of plant height, number of branches, internodal length and number of inflorescences. The study indicated that RH in the morning can be considered as the most influencing factor for plant growth under polyhouse condition. This agrees with findings of Bakker (1988) and Anbarasan (2002).

Crop in polyhouse took maximum number of days to flower. Minimum and maximum temperatures and RH in the morning had negative influence on earliness in flowering for Anagha in polyhouse. Minimum temperature and RH at noon negatively correlated with days to flower in the indeterminate variety. Lower light intensity negatively influenced days to flower in Anagha in polyhouse. Ho (1996) reported similar findings. Prevailing lower RH at morning and noon, higher maximum temperature and lower minimum temperature and lower light intensity might have delayed flowering in polyhouse. Positive correlation between comparatively lower maximum temperature and days to flower support early flowering of crop in open field. Maximum temperature had positive correlation with days to harvest in polyhouse. High light intensity in open field encouraged early fruit ripening as shown by negative correlation. Rainfall had indirect negative correlation with days to harvest in polyhouse.

When canonical correlation is considered along with simple correlation, the per cent variance explained also should be taken into consideration. So considering first two canonical correlations along with cumulative variance explained, we may infer that the crop characters were more related to the weather parameters under polyhouse condition. When the canonical correlation inclusive of rainfall is considered under polyhouse, the correlations are not so high leading to the inference that stray rainfall does not influence the crop directly as polyhouse act as a rain guard. But at the same time, the stray rainfall even favours the change in the other weather parameters.

The partial correlation clearly brings out the fact that polyhouse provides a much more congenial environment for the crop growth. It provides a guard against incessant and unexpected rainfall during the crucial stages of crop growth. At the same time, it modifies the environment for the crop to grow and ultimately gives better yield by way of an indirect control of the weather parameters especially maximum temperature irrespective of the variety and with minimum temperature, light intensity, rainfall and RH at noon as variety specific. Rajan (1989) reported negative correlation of tomato fruit yield per plant with minimum temperature. Thus the environment was made congenial for the higher yield in tomato as observed in polyhouse.

Summary

6. SUMMARY

An investigation to study the physiological aspects of tomato production under polyhouse and open field condition was conducted at the Department of Olericulture, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur from October 2005 to February 2006.

The experiment was laid out in a Randomized Complete Block Design with four replications. Two varieties viz, semideterminate, bacterial wilt and crack resistant Anagha and indeterminate LE 643 were used for the study. Observations on morphological, growth and yield attributes were recorded during the course of investigation. The daily weather parameters recorded inside the polyhouse and open field during the cropping period were used to compute the crop weather relationship. The salient results obtained during the course of investigation are summarized below.

1. Polyhouse crop of both varieties recorded higher plant height upto 30 DAT. Crop in open field recorded more plant height after that stage.

2. Growing condition had significant influence on the number of branches per plant. Open field crop had higher number of branches at all stages of study.

3. Plants in polyhouse had greater internodal length at all growth stages during the investigation.

4. Growing condition had a significant influence on Relative Growth Rate. At initial stages of study, open field crop had higher RGR whereas reverse situation was noticed at later stages.

5. Leaf area index was maximum under polyhouse condition at all stages irrespective of varieties.

6. Growing condition had a significant influence on NAR at final stage. Polyhouse crop had higher NAR at this stage whereas it was higher in open field crop at initial stages.

7.Open field crop had significantly higher CGR with respect to growing conditions at 15-30 days interval. But at later stage, polyhouse crop expressed higher CGR

8. Crop in open field was earlier for flowering and first harvesting.

9.Growing condition had significant impact on number of inflorescences. At every stage of study, higher number of inflorescences was recorded in polyhouse.

10. Fruit size was almost equal and was not influenced by growing condition. No significant impact was noticed over individual fruit weight but slightly higher fruit weight was observed in polyhouse.

11.Maximum number of fruits was harvested from polyhouse and number of harvests was also higher in polyhouse.

12. Growing condition did not significantly influence yield per plant. However higher yield was noticed in polyhouse.

13.Correlation between maximum temperature and plant height, number of branches, internodal length and number of inflorescences was significant irrespective of variety and growing condition. Days to flower and first harvest showed significant correlation with maximum temperature but the response varied with variety. Light intensity had significant correlation with days to flower and harvest. Significant negative correlation was noticed between plant characters and rainfall. Relative humidity in the morning had significant positive correlation with plant height, number of branches, internodal length and number of inflorescences. Significant correlation was noted between days to harvest and RH at noon.

14.Canonical correlation implies that, crop characters were more related to the weather parameters under polyhouse condition.

15.Significant partial correlation was noticed between crop yield and maximum and minimum temperatures in polyhouse condition. Relative humidity in the morning and light intensity had significant correlation with yield of LE 643 in polyhouse.

16.Disease incidence was comparatively higher under polyhouse condition. But good quality fruits with lower cracking percentage were harvested from polyhouse.

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Originals not seen

Abstract

PRODUCTION PHYSIOLOGY OF POLYHOUSE TOMATO (*Lycopersicon esculentum* Mill)

By

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ABSTRACT OF THE THESIS

submitted in partial fulfillment of the requirement
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ABSTRACT

Investigation on physiological attributes of yield in tomato was carried out at Department of Olericulture, College of Horticulture, Vellanikkara, Thrissur during October 2005 to February 2006 under two different growing conditions (polyhouse and open field). The experiment was laid out in Randomised Complete Block Design with four replications. Indeterminate LE 643 and semideterminate Anagha were the varieties used for the study.

The study revealed that crop raised in polyhouse showed more plant height (upto 30 DAT) and internodal length. Number of branches was higher in open field. Relative Growth Rate and Net Assimilation Rate were higher in open field compared to polyhouse at initial stages but at later stages, reverse situation was noticed. Crop growth Rate and LAI were maximum in polyhouse condition. Number of inflorescences and fruits per plant, number of harvests per plant, single fruit weight and fruit yield per plant were observed higher in polyhouse.

Maximum temperature and RH at morning had positive significant correlation with vegetative characters and number of inflorescences irrespective of growing condition. Maximum temperature and light intensity had significant correlation with days to flower. Rainfall showed negative correlation with plant characters. Canonical correlation revealed that crop characters were more related to the weather parameters under polyhouse condition. Significant partial correlation was noticed between crop yield and maximum and minimum temperature in polyhouse. Relative humidity at morning and light intensity had variety specific correlation with yield.

Pests and diseases incidence was comparatively higher in polyhouse condition due to higher temperature but cracking percentage was higher in open field. The fruit appearance and quality were comparatively better in polyhouse condition.